PROGRESS IN ENGINEERING APPLICATION AND TECHNOLOGY
e-ISSN: 2773-5303

PEAT

Vol. 7 No. 1 (2026) 623-633
https://publisher.uthm.edu.my/periodicals/index.php/peat

Mechanical and Thermal Properties of Bamboo Textile Waste Reinforced Recycled Polypropylene Composites for Sustainable Packaging Applications

Nur Ain Mohd Amin[1], Mazatusziha Ahmad[1,2]*, Reazul Haq Abdul Haq[1]

[1] *Department of Chemical Engineering Technology, Faculty of Engineering Technology Universiti Tun Hussein Onn Malaysia, 84600 Pagoh, Johor, MALAYSIA*

[2] *Bamboo Research Centre, Faculty of Engineering Technology Universiti Tun Hussein Onn Malaysia, 84600 Pagoh, Johor, MALAYSIA*

*Corresponding Author: maza@uthm.edu.my
DOI: https://doi.org/10.30880/peat.2026.07.01.070

Article Info

Received: 12 January 2026
Accepted: 20 February 2026
Available online: 25 May 2026

Keywords

Bamboo textile waste, PP, MAPP, alkaline treatment, mechanical properties, thermal properties, fibre content

Abstract

The rising amount of textile and plastic waste requires the need to find sustainable materials solutions using the principles of the circular economy. In this research paper, eco-friendly composites using recycled polypropylene (rPP) reinforced with alkaline-treated bamboo textile waste (BTW) with the use of MAPP as compatibilizer will be explored. The results of the alkaline treatment and fiber loadings from 5 to 25 wt% will help to evaluate its tensile and thermal properties. SEM and FTIR analysis aided in identifying the effectiveness of the removal and increase in the fiber's roughness due to the alkaline treatment. The composite with 5 wt% alkaline-treated BTW showed the highest tensile strength, and above that amount resulted in lower performance due to agglomeration and limited matrix wetting. TGA and DSC studies showed enhancement in thermal stability from the treatment. However, after reaching the critical amount, the stability of composites diminished.

1. Introduction

Malaysia has come forward as a major industrial and export-oriented country, with its infrastructure facilitating the textile and apparel industries for the last decade [1]. Malaysian textile manufacturing is a crucial sector for the supply and delivery of fabrics, yarn, and apparel [2]. Nevertheless, the apparel and textile industries alike pose the greatest level of damage to the environment and lead to huge water consumption and carbon emissions throughout their life cycles [3]. In addition, the disposal of textiles poses dangers to the environment, as the dumped materials tend to generate hazardous greenhouse gas emissions, such as methane, during decomposition [4].

Textile waste produced in the Malaysian industry is estimated to be 195,300 tons every year, with most being disposed of in landfills [5]. The decomposition process for textiles can take up to 200 years, which varies based on the type of material, with natural fibers decomposing faster compared to synthetic ones [5]. The application of a circular economy approach through recycling, re-use, or up-cycling has been touted to help minimize the problem of textile waste [5].

Textile waste can be categorized into pre-consumer and post-consumer waste. In the pre-consumer category, the waste comes from textiles produced but rejected during the manufacturing process, while post-consumer waste comprises discarded textiles and clothing [6]. In an effort to minimize the use of landfills,

methods such as textile waste recycling and reuse are being practiced across the globe. Textile fibers have been reused successfully in applications like soil reinforcement and blending of textile fibers to enhance the mechanical properties of yarns and reduce material waste [7][8].

The recent interest in bamboo fabrics has been spurred by their softness, breathability, moisture-wicking property, and antibacterial function, which qualifies them for applications in garments and interior textiles [9][10]. Nonetheless, although it is biodegradable, the increasing amount of bamboo fabric waste requires finding other strategies to handle it. Recycling bamboo fabric waste to make other items would slow down this material's disposal rate, minimize the need for new material usage, and conserve energy [11].

Despite the growing demand for sustainable materials, little work has been done on the use of bamboo textile waste as a reinforcing agent in polymer composites. This research aims to shorten the gap by evaluating the performance of bamboo textile waste as a reinforcing material in polymer composites, which may contributes to development of sustainable material [12]. Meanwhile, polypropylene (PP) is well known and widely used as a composite matrix due to its favorable thermal, mechanical and processing properties [13].

The effectiveness of recycled PP reinforced with natural fibers has been previously observed in various studies. For instance, Butylina et al. (2011) [14] proved that the addition of recycled PP with wood fibers resulted in materials with acceptable mechanical properties and the ability to decrease plastic wastage. Also, the works of Milosevic et al. (2017) [15] proved the remarkable increase in tensile strength and stiffness for recycled PP once natural fibers are incorporated, despite the difficulties related to its processing.

In general, the incorporation of bamboo textile wastes in recycled PP composites is considered a sustainable material design strategy that focuses on both textile and plastic wastes. The motivation for this research is to apply the principles of the circular economy by upcycling waste materials into higher-value composite materials for sustainable engineering applications [16].

2. Materials and methods

In this study, the bamboo fibre reinforced recycled PP composite was produced via an internal mixer, crusher and hot compression machine. The characterization of the untreated and alkaline-treated bamboo textile waste (BTW) was examined via Field Emission Scanning Electron Microscopy (FESEM) and Fourier Transform Infrared Spectroscopy (FTIR). Mechanical and thermal properties of specimens were done by using Universal Tensile Machine (UTM), Thermogravimetric Analysis (TGA) and Differential Scanning Calorimetry (DSC).

2.1 Bamboo Textile Waste and Recycled Polypropylene

The bamboo textile waste that was used in this experiment was purchased from Kapas Living Sdn. Bhd. with 2 meter long. The bamboo textile waste was cut into small size of 1x1cm to produce uniform sizes. Recycled polypropylene was collected from the post-consumer waste.

2.2 Alkaline Treatment

During this process, the bamboo textile waste was submerged in a 5% sodium hydroxide solution (NaOH) and rinsed entirely with distilled water few times to eliminate the excessive NaOH from the fiber surface. Lastly, the BTW was air-dried for 2 days under the sun then dried in an oven at 70°C for 4 hours for it to fully dry.

2.3 Composite Formulation

The composite composition and designation of materials in this study is shown in Table 2 and Table 3. The addition of bamboo textile waste fiber is in the range of 5 to 25 wt%. Table 1 and Table 2 shows the designation of control sample with polypropylene and designation of alkaline-treated and untreated BTW-rPP, respectively.

Table 1: Designation of pure and recycled PP

Sample	Designation
Pure PP (pPP)	100%
Recycled PP (rPP)	

Table 2: Designation alkaline-treated and untreated BTW-rPP

Sample Designation	rPP (wt%)	Bamboo Textile Waste (wt%)	MAPP (wt%)

Progress in Engineering Application and Technology Vol. 7 No. 1 (2026) p. 623-633

BTW-rPP 5	90	5	5
BTW-rPP 10	85	10	5
BTW-rPP 15	80	15	5
BTW-rPP 20	75	20	5
BTW-rPP 25	70	25	5

2.4 Preparation of Composites

The bamboo textile waste reinforced recycled polypropylene (BTW-rPP) composites were prepared with four equipment, which includes internal mixer, crusher, hot compression and laser cutting machine. The BTW-rPP was mixed with the presence of MAPP as a compatibilizer in the internal mixer at 170°C, speed of 40 rpm and 10 minutes per cycle. The molten composite then crushed to small sizes with a crusher then was shaped into a flat sheet by using a hot compression machine. The composites were cut into dumbbell-shaped sample which follows the standard ASTM D638 type IV via a laser cutting machine.

2.5 Characterization of Composites

2.5.1 Field Emission Scanning Electron Microscopy (FESEM)

Field Emission Scanning Electron Microscopy (FESEM) was used to examine the morphology and composition of the alkaline-treated and untreated BTW. The FESEM images provide high resolution view of the sample surface for the observation of features like fiber distribution and porosity. The imaging was performed at voltage of 5-15 kV.

2.5.2 Fourier Transform Infrared Spectroscopy (FTIR)

Fourier Transform Infrared Spectroscopy (FTIR) was employed to analyze the changes in chemical bonds and functional groups of the alkaline-treated and untreated BTW. The samples were run under the standard of ASTM E168 and ASTM E1252, where wavelength of 400 cm^{-1} to 4000 cm^{-1} were used.

2.6 Mechanical Testing of Composite

The mechanical properties of the composites were evaluated by its tensile strength, Young's modulus and elongation at break via Universal Testing Machine (UTM). The samples follow the standard of ASTM D638, in which the samples were cut into dumbbell-shaped. The UTM was run at 10kN with speed of 5mm/min.

2.7 Thermal Testing of Composite

2.7.1 Thermogravimetric Analysis (TGA)

Thermogravimetric Analyzer (TGA) was utilized to assess the thermal stability and degradation temperature of the samples by measuring weight loss as a function of temperature. The samples of BTW, PP and BTW-rPP were heated from 20°C to 500°C at 10°C/min under nitrogen temperature.

2.7.2 Differential Scanning Calorimetry (DSC)

Differential Scanning Calorimetry (DSC) was used to evaluate the changes in the amount of heat required as it undergoes controlled temperature changes. The samples of rPP and BTW-rPP were heated from 0°C to 200°C.

3. Results and Discussion

This chapter discusses the results of the conducted testings, in which the first part discusses the characterisation of BTW, followed by mechanical and thermal properties of alkaline-treated and untreated BTW-rPP composites.

3.1 Characterization of Bamboo Textile Waste (BTW)

3.1.1 Field Emission Scanning Electron Microscopy (FESEM)

Fig. 1 presented the FESEM image of the BTW fibers at 2000X magnification. The untreated BTW fibers in Fig. 1(a) shows the bundled structure of the individual fibers, which have been bonded together using natural adhesives, lignin and hemicelluloses. It is also evident from the image that the surface of each individual fiber has a smooth coat of lignin, with marked longitudinal stripes, which indicate that the natural waxes and hemicelluloses present on the fibers are non-polar substances and are hydrophobic in nature. This was also found by Das & Chakraborty in 2007[17], where they assess the enhancement of mechanical properties of bamboo fibers after being treated with alkaline NaOH. In the study, it was observed that the surface of the untreated bamboo fiber contains a smooth topography because it contains lignocellulosic compounds. Thus, it should be noted that NaOH treatment plays a crucial role in removing this topography to increase the surface roughness as well as availability of hydroxyl groups.

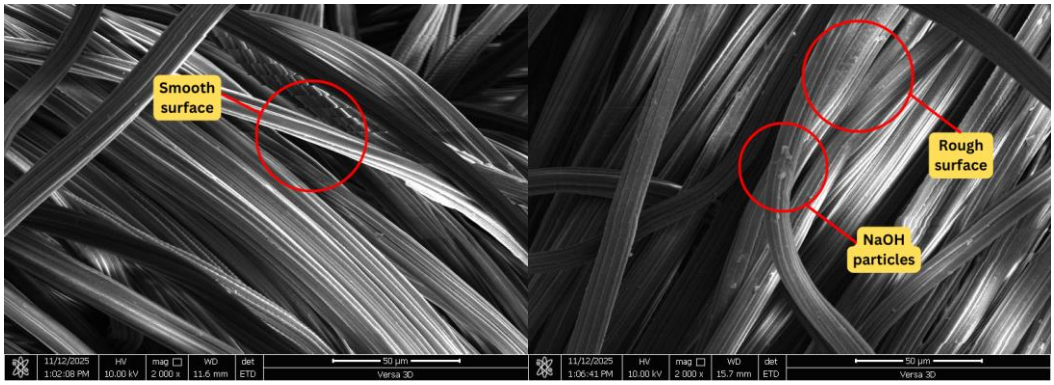


Fig. 1 FESEM images of (a) untreated BTW(b) alkaline-treated BTW

The FESEM image of alkaline-treated BTW reveal distinct differences in the surface of the fibers, which become very rough and wavy, as indicated in Fig.1(b). This indicates that NaOH treatment dissolves all non-cellulosic materials, thereby increasing the roughness of the surface. However, this treatment should further increase the surface area of the fibers by loosening bundles to individual entities. From observations, there seems to be no evidence that all fibers contribute to or merge to form individual entities that freely disintegrate. This might be due to the rigidity of woven bamboo textile, which indicate that woven layers or bundles of this bamboo textile could cap the highest adhesive surface area for binding to polypropylene.

3.1.2 Fourier Transform Infrared Spectroscopy (FTIR)

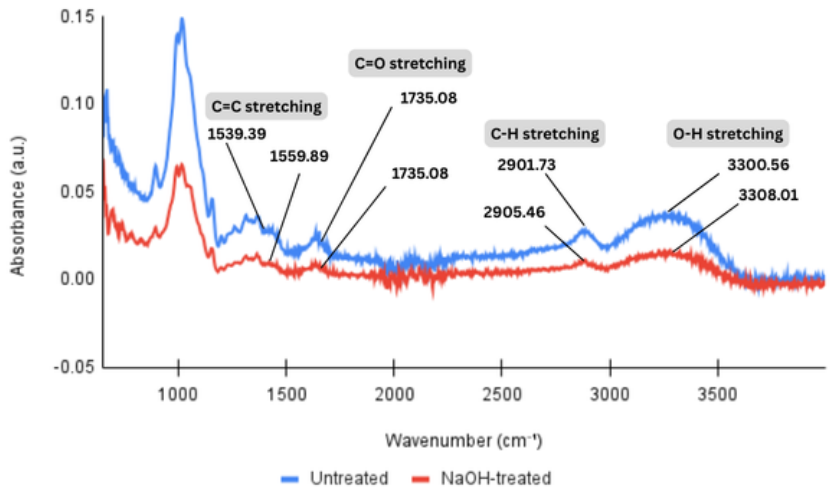


Fig. 2 FTIR spectrum of alkaline-treated and untreated BTW

Fig.2 depicts the FTIR spectrum of the BTW fibres, in which the untreated BTW fibre shows typical peaks for a lignocellulosic material. The broad peak between 3300 and 3500 cm^{-1} indicate absorption by O-H bonds due to strong hydrogen bonding in the cellulosic regions and physically adsorbed water. In addition, the peaks at

Progress in Engineering Application and Technology Vol. 7 No. 1 (2026) p. 623-633

2900 cm^{-1} indicate absorption by C-H bonds, and the absorption peak at 1730 cm^{-1} indicate C=O bonds in ester linkages in the hemicellulose portion of the lignocellulosic material. Hence, the peaks indicate the presence of lignocellulosic material in the untreated BTW fibres.

On the other hand, the spectrum for the alkaline-treated BTW fibres presented a well-resolved and more distinctive changes. Among these is the disappearance of the peak around 1730 cm^{-1}. This shows that saponification has occurred in the ester groups in the hemicellulose, as NaOH breaks the acetyl and uronic ester linkages that convert them to carboxylate ions and alcohols. Consequently, the loss of these non-cellular materials usually leads to the development of the crystalline cellulose structure. Also, the peak intensities in the region of lignin-related features around 1500-1600 cm^{-1} were weakened, indicating that lignin has partially been dissolved or degraded by the NaOH solution.

3.2 Mechanical Properties of BTW-rPP

In this section the discussions were focused on the effect of alkaline treatment on tensile properties of PP and BTW-rPP composites such as tensile strength, Young's Modulus and elongation at break. Table 4.1 shows the overall results of tensile properties at varied bamboo fibre content ranging 5% to 25%.

Table 4.1: Tensile properties of treated and untreated BTW-rPP

Composites	Sample Designation	Tensile Strength (MPa)	Young's Modulus (MPa)	Elongation at Break (%)
Untreated BTW-rPP	BTW/rPP 5%	2.1823	76.6676	2.6768
	BTW/rPP 15%	7.0365	99.9945	5.9909
	BTW/rPP 25%	5.0396	132.9812	3.6475
Treated BTW-rPP	BTW/rPP 5%	7.2865	84.1332	8.2465
	BTW/rPP 15%	6.7760	123.730	4.5111
	BTW/rPP 25%	1.9583	104.8254	1.5828

Table 4.1: Tensile properties of pPP and rPP

Composites	Tensile Strength (MPa)	Young's Modulus (MPa)	Elongation at Break (%)
pPP	7.7615	100.05	11.5152
rPP	11.8021	218.3744	4.1985

3.2.1 Tensile Strength of PP and BTW-rPP

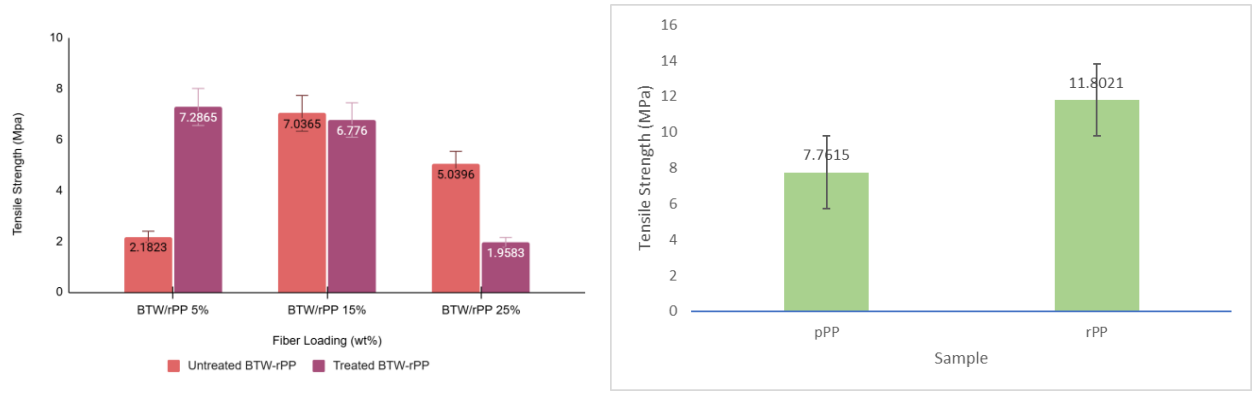


Fig. 3 Tensile strengths of (a) BTW-rPP (b) PP

The tensile strength of recycled polypropylene (rPP) in Fig. 3(b) is higher than that of pPP, with values of 11.80 MPa and 7.76 MPa, respectively, indicating superior tensile resistance of rPP. This improvement is attributed to molecular rearrangement and increased crystallinity induced by repeated thermal–mechanical processing during recycling. Similar trends were reported by Beg and Pickering (2008)[18], where rPP exhibited comparable or enhanced tensile strength relative to virgin PP.

Fig. 3(a) shows the tensile strength of BTW–rPP composites reinforced with untreated and NaOH-treated bamboo textile waste (BTW) at 5%, 15%, and 25% fiber loadings. For untreated composites, the highest tensile strength (7.04 MPa) was observed at 15% loading, followed by 25% and 5%. In contrast, treated composites exhibited decreasing tensile strength with increasing fiber content, mainly due to fiber agglomeration, poor packing efficiency, void formation, and reduced matrix continuity at higher loadings. As a result, 5% fiber loading was identified as the optimum for the treated composites.

3.2.2 Young's Modulus of PP and BTW-rPP

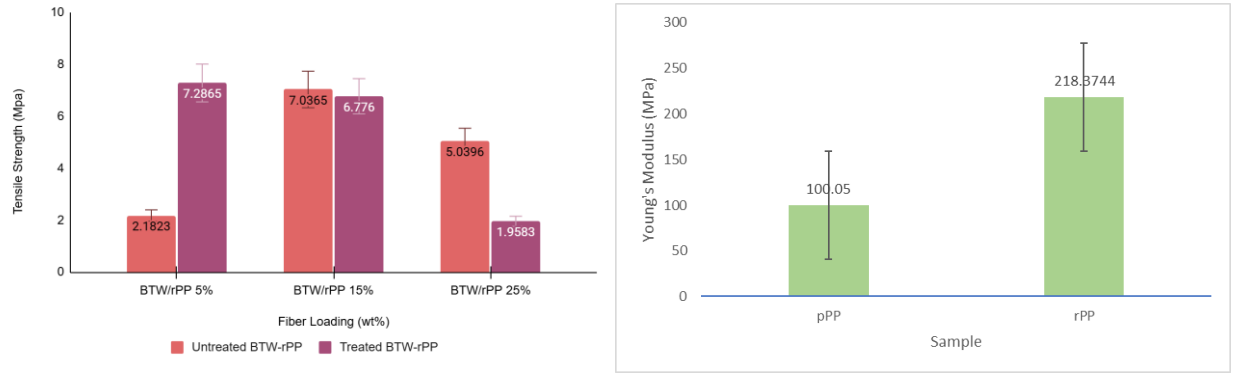


Fig. 4 Young's modulus of (a) BTW-rPP (b) PP

Fig. 4(a) presents the Young's modulus of treated and untreated BTW–rPP composites at varying fiber loadings. For both systems, the modulus increased from 5% to 15% fiber content due to the rigid nature of bamboo fibers. The alkaline-treated composites consistently exhibited higher stiffness than untreated ones, owing to improved fiber dispersion and stronger interfacial adhesion that restricted polymer chain mobility. However, at 25% fiber loading, the modulus of the treated composite decreased, likely due to fiber agglomeration and insufficient matrix wetting caused by the low bulk density and high volume fraction of treated fibers. A similar decrease in Young's modulus at high fiber loadings was reported by Darda et al. (2025)[19] for cotton fiber–PP composites, where limited matrix wetting reduced composite stiffness. This supports the trend observed in the BTW–rPP composites.

Fig. 4(b) shows the Young's modulus of rPP is twice more than that of pPP, at 218.37 MPa and 100.05 MPa, respectively, indicating significantly higher stiffness. This increase is attributed to higher crystallinity and reduced molecular mobility caused by chain scission during recycling, which is consistent with findings reported by Aurich et al. (2017)[20].

3.2.3 Elongation at Break of PP and BTW-rPP

Fig. 5(a) illustrates the elongation at break of treated and untreated BTW–rPP composites at fiber loadings of 5%, 15%, and 25%. For treated composites, elongation decreased with increasing fiber content, indicating a shift

Progress in Engineering Application and Technology Vol. 7 No. 1 (2026) p. 623-633

toward more brittle behavior. Untreated composites showed even lower elongation due to poor interfacial adhesion and fiber pull-out, which promote early crack initiation. In contrast, treated composites retained slightly higher elongation, reflecting improved stress transfer from enhanced fiber–matrix interaction. A similar reduction in elongation with increasing fiber loading was reported for jute fiber–PP composites by Shen et al. (2021)[21], attributed to matrix discontinuity, increased porosity, and restricted plastic deformation at higher natural fiber contents.

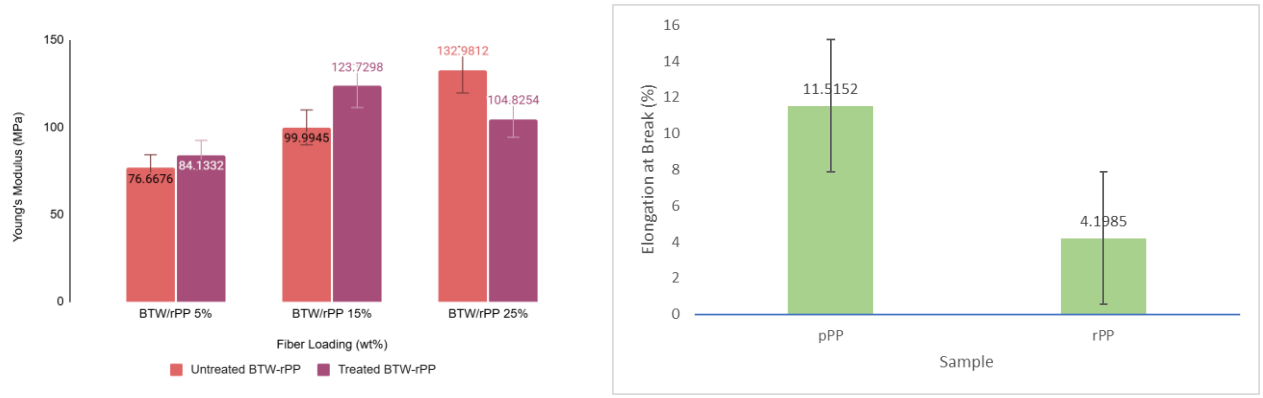


Fig. 5 Elongation at break of (a) BTW-rPP (b) PP

Fig. 5(b) shows that the elongation at break of rPP is significantly lower than that of pPP, at 4.20% and 11.52%, respectively, indicating reduced ductility after recycling. This reduction is attributed to polymer chain degradation and decreased molecular weight, which limit plastic deformation. Similar behavior has been reported by Al-Salem et al. (2009)[22], where rPP exhibited increased brittleness.

3.3 Thermal Properties of BTW-rPP

This section evaluates the thermal properties of BTW-rPP composites, BTW and PP using Thermogravimetric Analysis (TGA) and Differential Scanning Calorimetry (DSC). TGA was employed to characterize the thermal stability of the materials by monitoring mass loss as a function of temperature, enabling the identification of degradation profiles and temperatures. Meanwhile, DSC was utilized to examine the phase transitions of the composites in response to controlled temperature changes. This analysis provides data regarding the melting temperature (T_m), crystallization temperature (T_c) , and degree of crystallinity (X_c), as well as the glass transition behavior (Tg) of the polymer matrix.

3.3.1 Thermogravimetric Analysis (TGA)

Fig. 6 present the TG and DTG curves of treated and untreated bamboo textile waste (BTW) fibers, illustrating their thermal stability and degradation behavior. Both samples show minor weight loss below 100 °C due to moisture evaporation, with untreated fibers exhibiting slightly higher loss because of their greater hydrophilicity. TG graph in Fig. 6(a) shows that major mass loss occurs between 200°C and 350 °C, corresponding to the degradation of lignocellulosic components. The treated fibers exhibit a delayed onset of degradation and a steeper slope, indicating improved thermal stability after alkaline treatment. This enhancement is attributed to the removal of thermally unstable components such as hemicellulose and lignin, consistent with findings by Loganathan et al. (2017)[23].

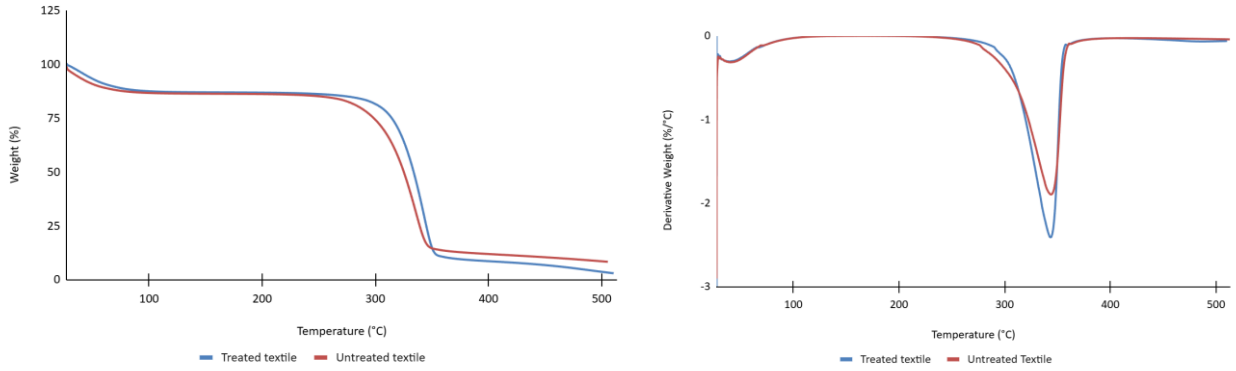


Fig. 6 Graphs of alkaline-treated and untreated BTW (a) TG and (b) DTG

The DTG curves show a dominant degradation peak at approximately 340 to 350°C for both samples, associated with cellulose decomposition. Untreated fibers display a broader, less intense peak, reflecting heterogeneous degradation from multiple components. In contrast, treated fibers exhibit a sharper DTG peak, indicating more uniform, cellulose-dominated degradation. Similar behavior has been reported for chemically treated natural fibers by Mohanty et al. (2005)[24]. Overall, the results confirm that alkaline treatment enhances the thermal stability and degradation uniformity of BTW fibers.

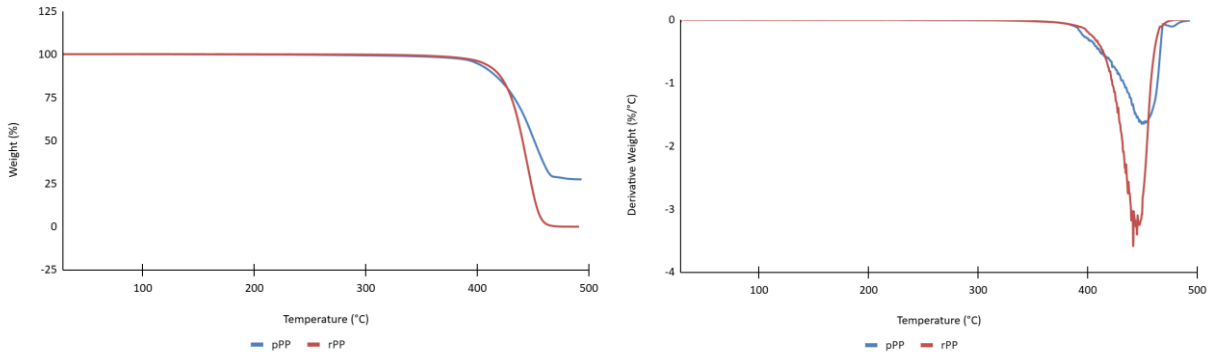
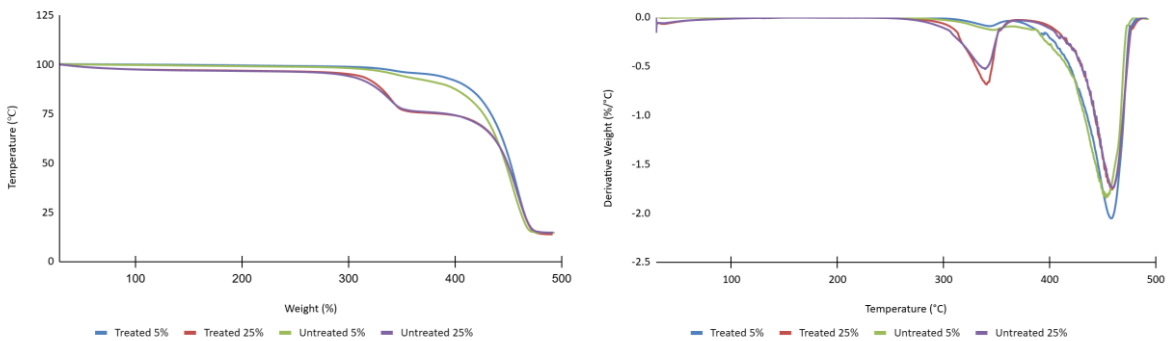


Fig. 7 Graphs of pPP and rPP (a) TG and (b) DTG

The TG and DTG curves of pPP in Fig. 7 show a single-step degradation behavior, with thermal stability maintained up to about 320°C and rapid decomposition occurring between 326.93°C and 445.07°C. The single DTG peak indicates uniform degradation and high material purity, confirming the good thermal stability of pPP. In contrast, rPP exhibits a lower degradation onset temperature and nearly complete mass loss, indicating reduced thermal stability due to chain scission and molecular weight reduction during prior processing and recycling. The broader DTG peak of rPP a less uniform degradation process, likely caused by impurities and oxidative degradation products. Overall, pPP shows superior thermal stability and more controlled degradation compared to rPP. However, despite its reduced stability, rPP retains a clear degradation profile, making it suitable for reuse in thermoplastic composites when processing conditions are properly controlled (Zhiltsova & Oliveira, 2025)[25].



Progress in Engineering Application and Technology Vol. 7 No. 1 (2026) p. 623-633

Fig. 8 Graphs of alkaline-treated and untreated BTW-rPP (a) TG and (b) DTG

The DTG curve of the 5 wt% untreated BTW–rPP composite (Figure 4.15) shows multi-stage degradation due to the presence of both bamboo fibers and the polypropylene matrix. A higher initial weight loss below 100 °C is observed compared to treated composites, caused by moisture in the hydrophilic untreated fibers. The main degradation between 250 °C and 380 °C corresponds to the decomposition of both BTW and rPP. The higher char residue and lower thermal stability indicate weak fiber–matrix interfacial bonding. At 25 wt% untreated BTW loading, the composite shows the highest weight loss (85.42%) and earlier degradation, with hemicellulose and cellulose decomposing between 300 °C and 350 °C, followed by rPP degradation up to 500 °C. Increasing untreated fiber content from 5 wt% to 25 wt% leads to higher moisture loss and earlier thermal decomposition due to the greater presence of thermally unstable components. In contrast, NaOH-treated BTW composites exhibit improved thermal stability and reduced early degradation. This agrees with Liu et al. (2008)[26], who reported enhanced thermal performance of alkali-treated bamboo fibers. Overall, alkaline treatment and controlled fiber loading are essential for improving the thermal stability of bamboo textile reinforced rPP composites.

3.3.2 Differential Scanning Calorimetry (DSC)

The differential scanning calorimetry (DSC) analysis of rPP, untreated BTW-rPP and Treated BTW-rPP demonstrates unique thermal behaviors influenced by the solvent interactions with the material structures. A comparative analysis of the DSC results for the samples illustrates how the NaOH treatment affects thermal transitions, crystalline structures, and the overall properties of the composite.

Table 4.5: Overall DSC data of the rPP, untreated and treated BTW-rPP

Composites	Sample Designation	T_m (□)	Heat, ΔH (J/g)	Heat of fusion, ΔH_f (J/g)	Degree of Crystallinity, X_c (%)
rPP	rPP	121.88	-57.35	57.35	0.277
Untreated BTW-rPP	BTW/rPP 5%	122.16	-52.97	52.97	0.269
	BTW/rPP 15%	121.89	-47.31	47.31	0.269
	BTW/rPP 25%	121.98	-40.33	40.33	0.260
Treated BTW-rPP	BTW/rPP 5%	123.16	-41.38	41.38	0.21
	BTW/rPP 15%	122.61	-46.27	46.27	0.263
	BTW/rPP 25%	121.96	-41.87	41.87	0.27

The DSC results in Table 4.5 show that recycled polypropylene (rPP) has a melting temperature (Tm) of 121.88 °C and crystallinity (Xc) of 0.277%. For untreated BTW–rPP composites, the melting temperature remained nearly unchanged (121.89–122.16 °C), indicating that untreated fibers did not affect the melting behavior of rPP. However, both the heat of fusion and crystallinity decreased with increasing fiber content, suggesting that untreated bamboo fibers hindered PP crystal formation due to poor fiber–matrix compatibility.

In contrast, treated BTW–rPP composites showed a slight increase in melting temperature, with the highest Tm (123.16 °C) observed at 5% fiber loading, reflecting improved thermal stability from better interfacial bonding. The crystallinity of treated composites was lowest at 5% loading but increased at higher fiber contents, reaching 0.27% at 25% BTW, indicating that treated fibers may act as nucleating agents. Overall, NaOH treatment improved fiber–matrix compatibility and modified the crystallization behavior, leading to enhanced thermal performance of the composites.

4. Conclusion

This study demonstrated the successful use of alkaline-treated bamboo textile waste (BTW) as reinforcement in recycled polypropylene (rPP) composites. Treatment with 5% NaOH effectively removed hemicellulose, lignin, and surface impurities, as confirmed by FTIR and FESEM, leading to improved fiber surface roughness and interfacial bonding. The mechanical performance of the composites strongly depended on fiber loading and treatment. The 5 wt% treated BTW–rPP composite showed the best balance of strength, stiffness, and ductility due to enhanced fiber–matrix adhesion aided by MAPP. Higher fiber loadings led to fiber agglomeration and void formation, reducing mechanical performance. Thermal analysis showed that alkaline treatment improved the thermal stability of bamboo fibers and slightly enhanced the thermal performance of the composites compared to untreated systems. DSC results indicated that fibers influenced the crystallinity of rPP, either by restricting chain mobility or acting as nucleating agents. Overall, this work confirms the feasibility of converting bamboo textile waste and recycled polypropylene into value-added composites, supporting circular economy principles by reducing both textile and plastic waste. Future work may explore alternative fiber treatments, optimized fiber loadings, and other recycled polymer matrices to further improve composite performance.

Acknowledgement

The author would like to thank the Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia for its support.

References

[1] Farhana, K., Mahamude, A. S. F., & Mica, M. T. (2022). The scenario of textile industry in Malaysia: A review for potentiality. Materials Circular Economy, 4(1). https://doi.org/10.1007/s42824-022-00063-5

[2] Malaysia Textile Manufacturing Market 2025-2034. (n.d.). MarkWide Research. https://markwideresearch.com/malaysia-textile-manufacturing-market/#:~:text=Malaysia%E2%80%99s%20textile%20manufacturing%20market%20encompasses%20both%20the%20production,textiles%2C%20technical%20textiles%2C%20and%20industrial%20textiles.%20Executive%20Summary

[3] Conca, K. (2015). An unfinished foundation. In *Oxford University Press eBooks*. https://doi.org/10.1093/acprof:oso/9780190232856.001.0001

[4] Team, E. (2024, October 1). How does textile waste affect the environment? The Environmental Literacy Council. https://enviroliteracy.org/how-does-textile-waste-affect-the-environment/#google_vignette

[5] Rashidi, Q. N. M. (2025, August 4). Textile waste poses a serious threat to the environment. thesun.my. https://thesun.my/malaysia-news/textile-waste-poses-serious-threat-to-environment-AL13905720

[6] Wang, F., Zhou, S., Li, L., & Zhang, X. (2017a). Changes in the morphological–mechanical properties and thermal stability of bamboo fibers during the processing of alkaline treatment. *Polymer Composites*, *39*(S3). https://doi.org/10.1002/pc.24332

[7] Rahman, S. S., Siddiqua, S., & Cherian, C. (2022, February). Sustainable applications of textile waste fiber in the construction and geotechnical industries: A retrospect. https://www.sciencedirect.com/science/article/pii/S2666790822000258

[8] Baloyi, R. B., Gbadeyan, O. J., Sithole, B., & Chunilall, V. (2023). Recent advances in recycling technologies for waste textile fabrics: a review. Textile Research Journal, 94(3–4), 508–529. https://doi.org/10.1177/00405175231210239

[9] W.ELL Fabric Editor. (2025, March 24). Bamboo fabric manufacturers revolutionize textile industry. W.ELL Fabric - Eco Fabric Supplier. https://wellfabric.com/bamboo-fabric-makers-transform-textiles/

[10] Maier, M. (2023, October 13). Is bamboo a good fabric for clothing? Is bamboo good for activewear? — SCI (Sport Casuals International). SCI (Sport Casuals International). https://www.sportcasuals.com/news/bamboo-good-activewear

[11] What happens to textiles when they are recycled?. (2024, December 24). Green City Recycler. https://greencityrecycler.com/what-happens-to-textiles-when-they-are-recycled-a-simple-guide/#:~:text=of%20landfills%20yearly.-,2.,the%20demand%20for%20these%20resources.

[12] Kim, K. J., & Kim, B. K. (1993). Crosslinking of HDPE during reactive extrusion: Rheology, thermal, and mechanical properties. Journal of Applied Polymer Science, 48(6), 981–986. https://doi.org/10.1002/app.1993.070480605

[13] Shubhra, Q. T., Alam, A., & Quaiyyum, M. (2011). Mechanical properties of polypropylene composites. *Journal of Thermoplastic Composite Materials*, *26*(3), 362–391. https://doi.org/10.1177/0892705711428659

[14] Butylina, S., Martikka, O., & Kärki, T. (2011). Physical and Mechanical Properties of Wood-Polypropylene Composites Made with Virgin and/or Recycled Polypropylene. *Polymer-Plastics Technology and Engineering*, *50*(10), 1040–1046. https://doi.org/10.1080/03602559.2011.557823
[15] Milosevic, M., Stoof, D., & Pickering, K. (2017). Characterizing the mechanical properties of fused deposition modelling natural fiber recycled polypropylene composites. *Journal of Composites Science*, *1*(1), 7. https://doi.org/10.3390/jcs1010007
[16] Mohanta, S., Mahalik, P., Hota, G. P., Sahoo, B. B., Pradhan, S. S., & Mohanty, S. P. (2023). Influence of surface-treatment of bamboo fiber on the physico-mechanical properties of bamboo fiber composites with virgin and recycled high-density polyethylene. Polymer Composites, 45(1), 914–923. https://doi.org/10.1002/pc.27825
[17] Das, M., & Chakraborty, D. (2007). Evaluation of improvement of physical and mechanical properties of bamboo fibers due to alkali treatment. *Journal of Applied Polymer Science*, *107*(1), 522–527. https://doi.org/10.1002/app.26155
[18] Beg, M. D. H., & Pickering, K. L. (2008). Reprocessing of wood fibre reinforced polypropylene composites. *Composites Part A*, 39(7), 1091–1100.
[19] Darda, M. A., Bhuiyan, M. a. R., Bari, M. A., Islam, S., & Hossen, M. J. (2025). Mechanically robust and thermally insulating natural cotton fiber-reinforced biocomposite panels for structural applications. *RSC Advances*, *15*(12), 9534–9545. https://doi.org/10.1039/d5ra00213c
[20] Aurich, J. C., Linke, B., Hauschild, M., Carrella, M., & Kirsch, B. (2017). Sustainability of additive manufacturing: A critical review. *Journal of Cleaner Production*, 146, 438–451
[21] Shen, J., Li, X., & Yan, X. (2021). Mechanical and acoustic properties of Jute Fiber-Reinforced Polypropylene composites. *ACS Omega*, *6*(46), 31154–31160. https://doi.org/10.1021/acsomega.1c04605
[22] Al-Salem, S. M., Lettieri, P., & Baeyens, J. (2009). Recycling and recovery routes of plastic solid waste (PSW): A review. *Waste Management*, 29(10), 2625–2643.
[23] Loganathan, S., Valapa, R. B., Mishra, R. K., Pugazhenthi, G., & Thomas, S. (2017). Thermogravimetric analysis for characterization of nanomaterials. In *Elsevier eBooks* (pp. 67–108). https://doi.org/10.1016/b978-0-323-46139-9.00004-9
[24] Mohanty, Smita & Nayak, Sanjay. (2010). Short Bamboo Fiber-reinforced HDPE Composites: Influence of Fiber Content and Modification on Strength of the Composite. Journal of Reinforced Plastics and Composites. https://www.researchgate.net/publication/249356696_Short_Bamboo_Fiber-reinforced_HDPE_Composites_Influence_of_Fiber_Content_and_Modification_on_Strength_of_the_Composite
[25] Zhiltsova, T., & Oliveira, M. S. A. (2025). Sustainable Polypropylene Blends: Balancing Recycled Content with Processability and Performance. *Polymers*, *17*(11), 1556. https://doi.org/10.3390/polym17111556
[26] Liu, Yanping & Hu, Hong. (2008). X-ray diffraction study of bamboo fibers treated with NaOH. Fibers and Polymers. 9. 735-739. 10.1007/s12221-008-0115-0.