



Effect of mercerization on the mechanical and thermal response of hybrid bagasse fiber/ CaCO_3 reinforced polypropylene composites

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ARTICLE INFO

Keywords:

Mercerization
Bagasse fiber
Hybrid composites
Polypropylene
Mechanical properties
Thermal analysis

ABSTRACT

This study evaluated the effect of sodium hydroxide mercerized bagasse fiber (BF) on the mechanical and thermal properties of polypropylene composites reinforced with hybrid BF/calcium carbonate (CaCO_3). Samples were fabricated with a compression molding machine and characterized for tensile, flexural, and thermal properties. Hybrid composites with mercerized BF (HMC) exhibited improved mechanical properties than the unmercerized hybrid composite (UHC), single-component composite (SC) and control sample. Additionally, TGA/DTG analysis revealed that the HMC were more thermally stable in comparison with other samples. Crystallinity index of HMC was about 24% higher than UHC, as indicated by XRD analysis. SEM images showed good interfacial adhesion in the morphology of HMC compared to UHC, which contributed to the improved thermal and mechanical properties exhibited by HMC. These results indicated that mercerization treatment and reinforcement hybridization could be utilized for improving the thermal and mechanical responses of natural fiber reinforced polypropylene composites.

1. Introduction

Polymer matrix composites are characterized by moderate stiffness, low cost, and simple manufacturing principles. They can be reinforced with particles and fibers in either synthetic or natural form. Commonly used particulate fillers include calcium carbonate [1], talc [2], and silica [2]. Due to environmental awareness and the finite availability of petroleum-derived fibers, research attention has been shifted to natural fibers. More so, they are characterized by low cost, light weight, high specific modulus, renewability and biodegradability [3,4]. Thus, these advantages make them highly competitive reinforcing materials in polymer composites.

Despite the advantages offered by natural fiber composites, incompatibility between the polymer matrix and fiber surface has been identified as major challenge in the processing of polymer composites containing natural fibers [3]. This results in wetting problem, weak interfacial adhesion, and limited stress transfer between the two interfaces, which greatly impacts strength development. However, some treatment protocols have been developed to alleviate this challenge, which include use of compatibilizers [5], coupling agents [6,7], and mercerization treatment [3,4].

Coupling agents such as coconut oil [7] and 3-(trimethoxysilyl) propyl methacrylate [8] have been used for enhancing compatibility between natural fibers and polymer matrices. Although improved properties are reported, there is a limit to this improvement. Due to aggregation not all the fibers are exposed to the coupling agent. Thus, fiber adhesion to the matrix may not be fully developed [9]. Fiber-matrix interfacial adhesion has also been improved using compatibilizers like polyethylene co-acrylic acid [5], maleic anhydride [10], and maleic anhydride grafted polypropylene [11]. The efficacy of compatibilizers is, however, limited by their dispersion on the fibers. Non-uniform dispersion negatively impacts fiber/matrix interfacial adhesion and limits the properties of the composites [9].

Mercerization is an alkali treatment process that is used to reduce lignin, hemicellulose, wax and oils that are present on the surface of fibers [3]. In addition, other changes that occur in the fiber include increased surface roughness, enhanced wettability, and decreased moisture absorption. This treatment, therefore, increases interfacial bonding strength and enhances the mechanical properties of the composites [3,4]. The effectiveness of the mercerization treatment depends on the concentration of the alkali, type, treatment time, and temperature [3,4]. Different alkalis have been investigated but sodium

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<https://doi.org/10.1016/j.polymeresting.2019.03.021>

Received 21 January 2019; Received in revised form 22 February 2019; Accepted 22 March 2019

Available online 26 March 2019

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hydroxide (NaOH) is widely used [3,4,12].

Several types of natural fibers and their derivatives, such as jute [13], kenaf [14], sisal, palm kernel shell [15], coconut shell [16], and bagasse [17–19], have been investigated as reinforcements in polymer matrix composites. Bagasse is a bio-product of sugarcane fiber obtained after the extraction of cane juice from sugarcane. However, this bagasse is mainly utilized as a form of fuel in the sugarcane mill furnaces despite its low caloric power. Therefore, its incorporation into polymer composites is considered as a viable option for ameliorating the challenges of disposing bagasse fibers.

In a report, the effect of pulverized bagasse fibers on the tensile and hardness properties of polyester composites was investigated. The authors concluded that these properties were greatly enhanced at 10 wt% bagasse reinforcement [17]. Similarly, another research investigated the toughness of bagasse/polyester composites by means of Charpy test. Results from the work showed that the fibers increased the notch toughness of the composites [20]. Other studies on bagasse fiber/polypropylene composites showed that the fibers increased tensile stiffness [18,19].

Other than the aforementioned treatment protocols, hybridization of reinforcements is another alternative that is actively being investigated. It involves the incorporation of more than two types of reinforcement materials into a polymer matrix. Thus, the composite possesses a synergy of the individual advantages of each reinforcement, enhanced performance and reduction in production cost [21]. Hybridization also offers an opportunity to tune the properties of the resulting composite [22]. Some previous studies have shown that hybridization improves some mechanical properties of polymer composites [21–23]. However, no such studies exist on hybrid bagasse fiber/CaCO₃ polypropylene composites.

Based on these earlier studies, the present research was carried out to develop hybrid polypropylene composites using synthetic CaCO₃ and chemically modified bagasse fiber reinforcements. The hybrid reinforcements are expected to give a favorable synergy to enhance the thermal and mechanical properties of polypropylene composites. The effect of mercerization treatment of bagasse fibers on the properties of the composites was also investigated.

2. Materials and methods

The materials that were used for this research are as shown in Table 1. The chemicals were procured from allied stores in Edo State, Nigeria while the homopolymer polypropylene (PP) from REPOL, a Reliance Polymer Product Manufacturer in India was obtained from chemical and allied store in Lagos State, Nigeria. The bagasse strands were acquired from a farm plantation in Akure, Ondo State, Nigeria. Calcium carbonate (CaCO₃) powder with an average particle size of ~10 µm was procured from Pascal Scientific in Akure, Ondo State, Nigeria.

Table 1
Raw materials and chemicals used.

Raw materials	Molecular weight (g/mol)	Chemical formula	Appearance
Homopolymer PP	42.080	C ₃ H ₆	Solid
Bagasse fiber	–	–	Solid (strands)
Diethyl phthalate (DOP)	390.564	C ₂₄ H ₃₈ O ₄	Liquid
Calcium carbonate (CaCO ₃)	100.087	CaCO ₃	Powder
Zinc stearate	632.332	C ₃₆ H ₇₀ O ₄ Zn	Powder
Sodium hydroxide	39.997	NaOH	Solid

2.1. Mercerization of bagasse fiber

The as-received bagasse fibers (BF) were washed thoroughly with distilled water and dried in a KX350A KENXIN drying oven for 24 h at 60 °C to condition the fibers and reduce the moisture content. Mercerization treatment was carried out on a part of fibers by treating them with 1M NaOH at 50 °C for 4 h in an ultrasonic water bath followed by washing with distilled water to attain a neutral status as confirmed by a litmus paper test. The mercerized (treated) fibers after washing were later oven-dried at 60 °C for a further 24 h. The remaining fibers were used in the unmercerized (untreated) form. Images of the as-received bagasse and mercerized BFs are shown in Fig. 1(a) and (b). Prior to the fabrication of the composites, the mercerized and unmercerized fibers were conditioned in an oven at 30 °C for 2 h.

2.2. Composite development

Composites were developed with a compression molding machine after compounding the CaCO₃/BF in various weight percent (wt.%) based on the predetermined proportions of 3, 6, 9, 12 and 15 wt.% of CaCO₃ with respect to the total weight of the composite (polypropylene, CaCO₃ and BF). Both mercerized/treated and unmercerized/untreated fibers were used for producing separate sets of the hybrid composites. Molding was done at 4 MPa and 160 °C for 10 min. In addition to the compositions above, selected single-component samples were developed for comparison as follows: low content mercerized bagasse (LB); high content mercerized bagasse (HB); low content CaCO₃ filler (LF) and high content CaCO₃ filler (HF). The formulations are shown in Table 2. After the molding process, samples were removed from mold and allowed to cool at room temperature. For single-component samples LB and HB, only mercerized fibers were used.

2.3. Characterization of samples

2.3.1. Flexural test

Three-point bend test was performed on the test samples in compliance with ASTM D790-15 standard. The length, width and thickness of the specimen were 120, 12.7 and 3.2 mm, respectively. The test was performed on INSTRON 5980-series Floor Model Universal Tester at a crosshead speed of 0.3 mm/mm and strain rate of 10^{−3}/s. The test was stopped when the specimen reached 5% deflection or breaks before 5% deflection. The experiment was carried out at room temperature of 22 ± 2 °C. Six repeatability tests were conducted for each sample and their mean values were used in this study to ensure accuracy and reliability of test results.

2.3.2. Tensile test

Tensile test was performed in compliance with ASTM D638-14 test standard. The specimen's overall length, gauge length, width and thickness were 115, 33, 10 and 5 ± 1 mm, respectively. The test was performed using INSTRON 5980-series Floor Model Universal Tester at a fixed crosshead speed of 10 mm/min. The experiment was carried out at room temperature of 22 ± 2 °C. Six repeatability tests were conducted for each sample and their mean values were used in this study to ensure accuracy and reliability of test results.

2.3.3. Fracture surface characterization

The fractured surfaces of the samples were examined by means of Phenom ProX scanning electron microscope (SEM) with operated at 15 kV. The samples were washed, cleaned thoroughly, air-dried and gold coated to make them conductive before SEM observation using Quorum coating machine (Q150RES).

2.3.4. Thermogravimetric analysis

Thermogravimetric analysis (TGA) and derivative thermogravimetric analysis (DTGA) were done using a TGA6 thermogravimetric

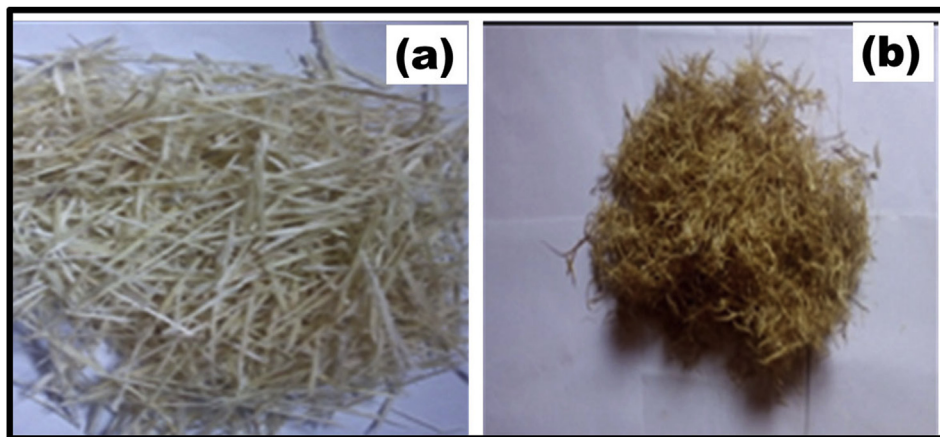


Fig. 1. Images of (a) unmercerized bagasse fibers (b) mercerized bagasse fibers.

Table 2

Composite formulation.

Sample	Weight fraction of CaCO_3 (wt. %)	PP (g)	CaCO_3 (g)	Bagasse fiber (g)	DOP (g)	Zinc stearate (g)
A	3	400	15	85	3	1.5
B	6	400	30	70	3	1.5
C	9	400	45	55	3	1.5
D	12	400	60	40	3	1.5
E	15	400	75	25	3	1.5
LF	3	485	15	–	3	1.5
LB	0	475	–	25	3	1.5
HF	15	425	75	–	3	1.5
HB	0	415	–	85	3	1.5
Control	Control	500	–	–	3	1.5

analyzer (Perkin Elmer) under nitrogen atmosphere with a flow rate of 20 mL/min and 10 °C/min heating rate over a temperature range of 50 °C–850 °C. A test sample of 5 mg was used for each run.

2.3.5. X-ray diffraction (XRD) study

Shimadzu X-ray diffraction equipment (LabX XRD-7000) under $\text{CuK}\alpha$ radiation [$\lambda = 1.5418 \text{ \AA}$] was used to identify the phases in the developed composites. Scanning was done between $2\theta = 10\text{--}50^\circ$ at a scanning speed of 4 deg/min.

3. Results and discussion

3.1. Flexural strength at peak

Fig. 2 shows the peak flexural strength of both mercerized and unmercerized BF/ CaCO_3 hybrids, single-component composites, and the control sample.

For the hybrid composites, the flexural strength increased as the proportion of the CaCO_3 increased from 3 to 15 wt.% for both mercerized and unmercerized BF addition. However, it was observed that mercerized BF hybrid composites possessed higher flexural strength than those of unmercerized BF hybrid composites. The mercerized BF reinforced hybrid composites also exhibited higher flexural strength compared with single-component composites (Samples LF, HF, LB, and HB), as well as the unreinforced polypropylene (control sample). Sample E (with 15 wt.% blend of CaCO_3 and mercerized BF) possessed the highest flexural strength value of 21.75 MPa compared to 17.51 MPa from similar composition with unmercerized Sample E. Compared with the 9.44 MPa recorded for the control sample, the flexural strength of Sample E (with mercerized BF) was 130% higher. This could be attributed to the short fiber interlocked with CaCO_3 and

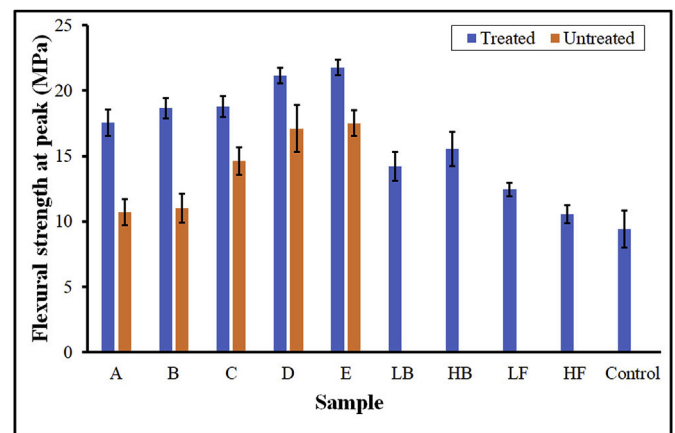


Fig. 2. Plot of flexural strength of samples.

the matrix, which enhanced good interfacial adhesion and effective stress transfer at the interface. This explanation is in line with the results and submission of some previous works [21,24].

3.2. Flexural modulus

Fig. 3 shows the plot of flexural moduli of the samples. All the composite samples exhibited higher flexural moduli than the control sample.

An initial increase in moduli was observed for Samples A to C, for

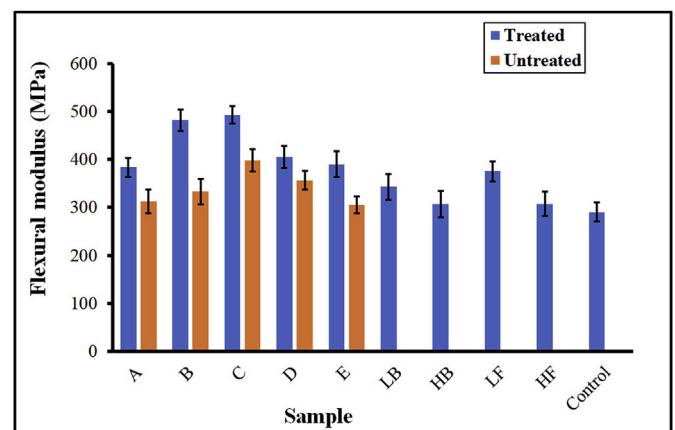


Fig. 3. Flexural moduli of composite and control samples.

both mercerized and unmercerized BF hybrids. However, the flexural moduli of Samples D and E showed a decline. For the hybrid samples, those with mercerized fibers had higher moduli compared with their counterparts containing unmercerized fibers. This observation is similar to the results presented in Fig. 2. The modulus of mercerized Sample C was 70% higher than the 290.56 MPa of the control sample. This enhancement could be attributed to the good interfacial adhesion between the reinforcements and matrix. This finding also agreed with the reports of previous researchers [1,20].

Considering the samples with single reinforcement, it was observed that low wt.% of either BF or CaCO_3 gave the best results. It was noted in the literature [25] that flexural modulus was high for low filler loading and decreased as filler loading increased for fly ash-filled polypropylene composites. This implied that stiffness was enhanced by low composition of the individual reinforcement. In this group, the highest modulus of 375.45 MPa was from Sample HF (3 wt% CaCO_3), followed by Sample LB (3 wt% BF). Comparing all the samples, the hybrid composites yielded higher moduli values.

3.3. Tensile strength at peak

Fig. 4 shows tensile strength at peak for all the samples. Similar to the results of flexural strength, the tensile strengths of the hybrid samples increased from Sample A through E, as the fraction of CaCO_3 increased.

Also, mercerized Sample E possessed the highest tensile strength of about 75 MPa. This similar trend was observed for the single-component composites, where the tensile strength of Sample HB (48.84 MPa) was higher than the other samples in this group. This was due to good interfacial adhesion that existed at this higher fiber loading. The unreinforced polypropylene possessed the least value of about 30 MPa and the percentage enhancement of the tensile strength at peak between the best sample and the control was 150%. This suggested that hybridization in composite development is a good approach to strengthening composite materials.

3.4. Tensile modulus

Fig. 5 shows the tensile modulus against reinforcement content for mercerized and unmercerized BF/ CaCO_3 hybrid and single-component composites as well as control sample. It was noticed that all the composites displayed higher modulus than the unreinforced polypropylene sample. However, hybrid composites showed outstanding performance than the single-component composites.

It was observed that the tensile moduli of mercerized BF/ CaCO_3 composite samples increased from Sample A to D before this property decreased in Sample E. On the other hand, moduli of unmercerized BF/

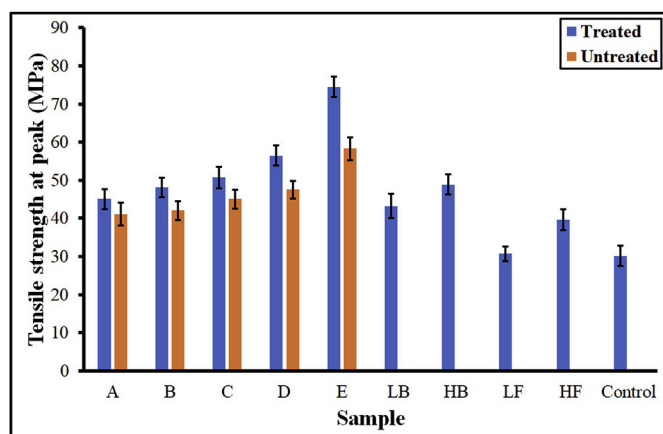


Fig. 4. Tensile strength at peak of composite and control samples.

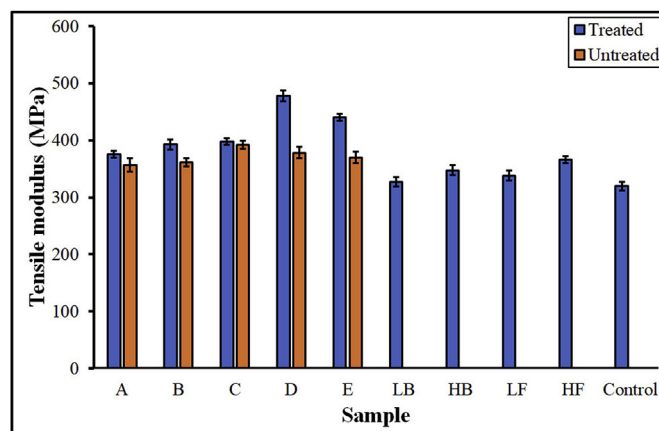


Fig. 5. Tensile moduli of samples.

CaCO_3 composite samples increased from Sample A through C, before decreasing from Sample D to E. This implied that the tensile modulus enhancement was achieved within this range of reinforcement contents similar to what was obtained in Fig. 2.

It could be seen from the trend of the results that both flexural and tensile strengths (Figs. 1 and 4) increased as the reinforcement content in hybrid composites increased in which the influence of the CaCO_3 was highly significant but the reverse was the case for both flexural and tensile moduli (Figs. 2 and 5) in which the best modulus was achieved at an optimum reinforcement content within 9 and 12 wt.%. At these contents, the effect of the BF was highly significant on the enhancement (Table 2). The results, therefore, revealed that enhancement in strength was highly supported by particulate CaCO_3 , a synthetic particle while enhancement in modulus was highly supported by BF, a natural fiber when used in the mercerized condition. Therefore, surface modification is an essential production process for natural fiber application in composite development for improved properties. This is in agreement with the findings and conclusion from the works of some previous authors [19,24].

Hybrid composite Sample D (with 12 wt.% CaCO_3) gave the best tensile modulus value of 477.95 MPa. This finding was due to the synergetic effects of the incorporated CaCO_3 and mercerized BF that yielded improvement in the tensile modulus of the composites, however, further increase in the filler/fiber content tended to reduce the strengthening capacity. The trend of this study was found similar to the research carried out by Leong et al. [26], which showed that at high filler loading with the intention of replacing talc with CaCO_3 , the tensile modulus of polypropylene composites gradually decreased as the CaCO_3 content increased. Also, considering the single-component composites, they also performed considerably well because of high compatibility of the reinforcement at the interface. However, the unreinforced polypropylene gave the least outcome with value of 319.72 MPa while the high CaCO_3 reinforced composite (HF) gave the best tensile modulus among the single-component composites with a value of 365.75 MPa which can be attributed to the stiffness and rigidity of the reinforcing filler. The percentage enhancement of the tensile modulus peak between the best sample and the control is given as 49.49%.

3.5. X-ray diffraction study

To compare the effect of mercerization, representative X-ray diffraction patterns of mercerized and unmercerized Sample E are presented in Fig. 6. The patterns showed the signature crystalline peaks of the polypropylene (PP) matrix. A summary of the crystalline peaks and their assigned crystallographic planes, according to the results in Ref. [27], are outlined in Table 3. Other than the PP peaks, the peak

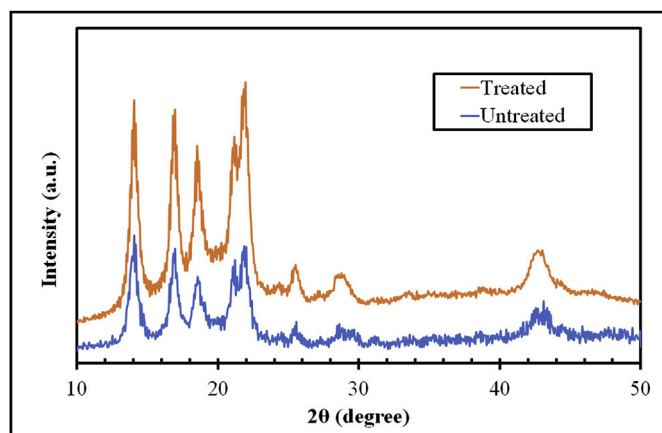


Fig. 6. X-ray diffraction patterns of mercerized and unmercerized bagasse/ CaCO_3 hybrid composites.

appearing at $2\theta = 42.95^\circ$ was assigned to CaCO_3 [15]. Most of the high intensity crystalline peaks appeared between $2\theta = 14.05^\circ$ – 42.95° , whereas the amorphous peaks of PP were at $2\theta = 20.45^\circ$ (117 plane) and 27.25° (220 plane).

It was also observed that characteristic biomass peaks, usually seen at $2\theta = 16.80^\circ$ and 22.30° [27,28] were not distinctly clear and appeared to have overlapped with PP peaks. Furthermore, the diffractogram of the hybrid sample with mercerized bagasse appeared sharper with higher intensities than the unmercerized sample. This implied that the mercerization treatment impacted more crystallinity to the mercerized sample, which agreed with the result presented in Refs. [19,24].

To support this observation, the crystallinity indices of Sample E with both mercerized and unmercerized fibers were evaluated by deconvoluting the diffractograms presented in Fig. 6 using Lorentzian profiles. Peak $2\theta = 42.95^\circ$ was excluded from deconvolution being that it was assigned to CaCO_3 . Peak deconvolution was done using Microsoft Excel and the crystallinity index was calculated using the following expression [27]:

$$\text{Crystallinity index (\%)} = \frac{A_{\text{crystalline}}}{A_{\text{total}}} \times 100 \quad (4)$$

where $A_{\text{crystalline}}$ is the summation of areas of the deconvoluted crystalline peaks and A_{total} is the total area of the estimated profile of all the peaks after deconvolution (see Fig. 7). Results showed that the mercerized fiber sample had the higher index of 63.97% compared with the 51.50% exhibited by the sample with unmercerized fiber. This result, therefore, indicated that mercerization increased the crystallinity of the sample. This could be ascribed to the elimination of the amorphous regions, such as lignin and hemicellulose covering the external surface of the fiber cell wall and exposed the fiber short-length crystallite [3,4].

3.6. Thermo-gravimetric analysis (TGA)

Fig. 8 (a) shows the TGA thermographs of the samples. The interpretation of the legend are as follows treated hybrid (mercerized Sample E), untreated hybrid (unmercerized Sample E), control sample, bagasse fiber (Sample HB), and calcium carbonate (Sample HF). The plots showed that all the composites exhibited better thermal stabilities compared to the control sample. Three degradation stages were noted

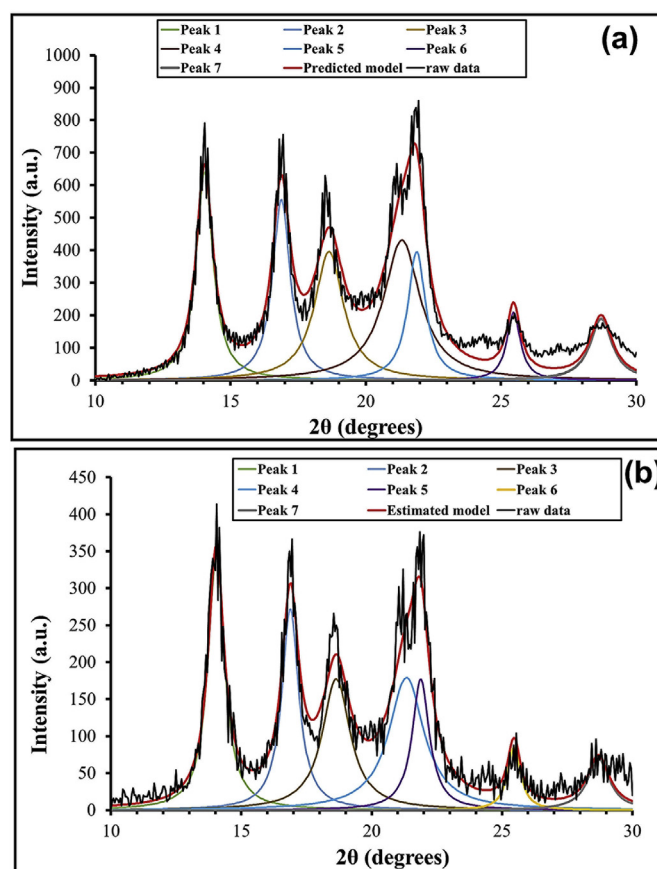


Fig. 7. Deconvoluted X-ray diffractograms of Sample E containing (a) mercerized fiber (b) unmercerized fiber.

from the thermographs. The first degradation temperature ranged from 50 to 150°C , which could be ascribed to the evaporation of moisture and other volatile matter. The second degradation stage was observed at a temperature range of 150 – 250°C , which indicated the loss of hemicellulose content. The third stage at about 250 – 400°C was attributed to the degradation of cellulose and lignin [21].

Between the two variants of Sample E (treated hybrid and untreated hybrid), unmercerized Sample E degraded at a lower temperature compared to the mercerized variant. This could be ascribed to the higher hydrophilicity and higher amorphous content of the BF in the unmercerized state. The highest thermal stability was seen in mercerized Sample E due to its higher crystallinity. The single-component composites (Samples HB and HF) had higher thermal resistance than the control sample. Of all the samples, mercerized Sample E, with hybrid reinforcement, possessed better thermal stability than the single-component composites due to hybridization.

Fig. 8 (b) shows the derivative thermo-gravimetric analysis of the samples in Fig. 8 (a). All the composites had higher degradation temperature than the control sample. It was also observed that the hybrid composites (both variants of Sample E) possessed higher degradation temperature compared to the single-component samples. Mercerized Sample E (treated hybrid) had the optimum degradation temperature with a value of 329°C , followed by unmercerized Sample E (untreated

Table 3

Data of crystalline peaks, planes, and crystallinity indices of a representative hybrid composite sample (Sample E with mercerized and unmercerized bagasse fibers).

	Plane	110	040	030	111	041	060	220	Crystallinity index (%)
With mercerized BF	$2\theta (^\circ)$	14.05	16.82	18.52	21.30	21.85	25.65	28.85	63.97
With unmercerized BF	$2\theta (^\circ)$	14.05	16.85	18.65	21.05	21.95	25.45	29.20	51.50

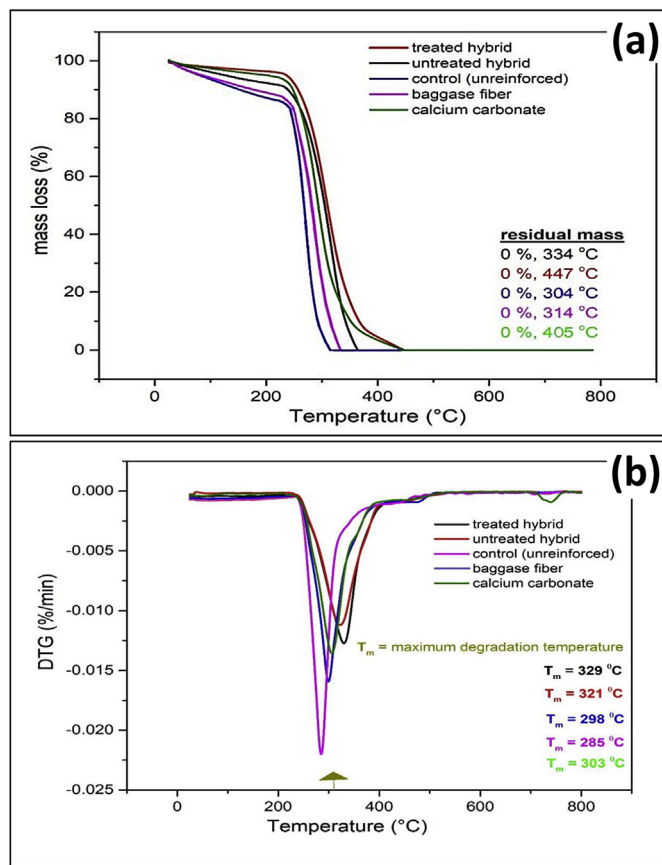


Fig. 8. (a) TGA thermographs and (b) Derivative TGA thermographs of selected samples.

hybrid) with a value of 321 °C. The unreinforced polypropylene (control sample) displayed the lowest degradation temperature of 285 °C.

3.7. Fracture surface characterization

Fig. 9 shows the fracture surfaces of mercerized and unmercerized Sample E, as well as the control sample. From the image of the hybrid mercerized composite in Fig. 9 (a), micro voids were virtually absent, and fiber-matrix de-cohesion was not observed. These observations strongly suggested that a strong interfacial interaction existed between the fiber and the matrix. Similar microstructural observations have been observed with use of compatibilizers [5,10] and mercerization treatment [1]. Furthermore, enhancement in the results of the mechanical characterizations in Figs. 2 and 4 are in good agreement with this observation from the SEM image. However, for the hybrid non-mercerized composite in Fig. 9 (b), evidences of fiber pull-out (white arrow) and micro-voids (black arrow) could be seen. This is an indication of the poor interfacial interaction between the matrix and the unmercerized fibers. The image of the fractured surface of the unreinforced polypropylene, as shown in Fig. 9 (c), was relatively rough, an evidence of brittle fracture. Therefore, it was concluded from these observations that mercerization treatment resulted in enhanced interfacial bonding between the fibers and the polymer matrix.

4. Conclusions

The investigation into the influence of mercerization of BF and hybridization of reinforcements on the mechanical and thermal responses of polypropylene composites revealed that:

- Samples from mercerized BF/CaCO₃ hybrid reinforcement gave the best results in mechanical properties. Improved mechanical properties were achieved in hybrid composites than the single-

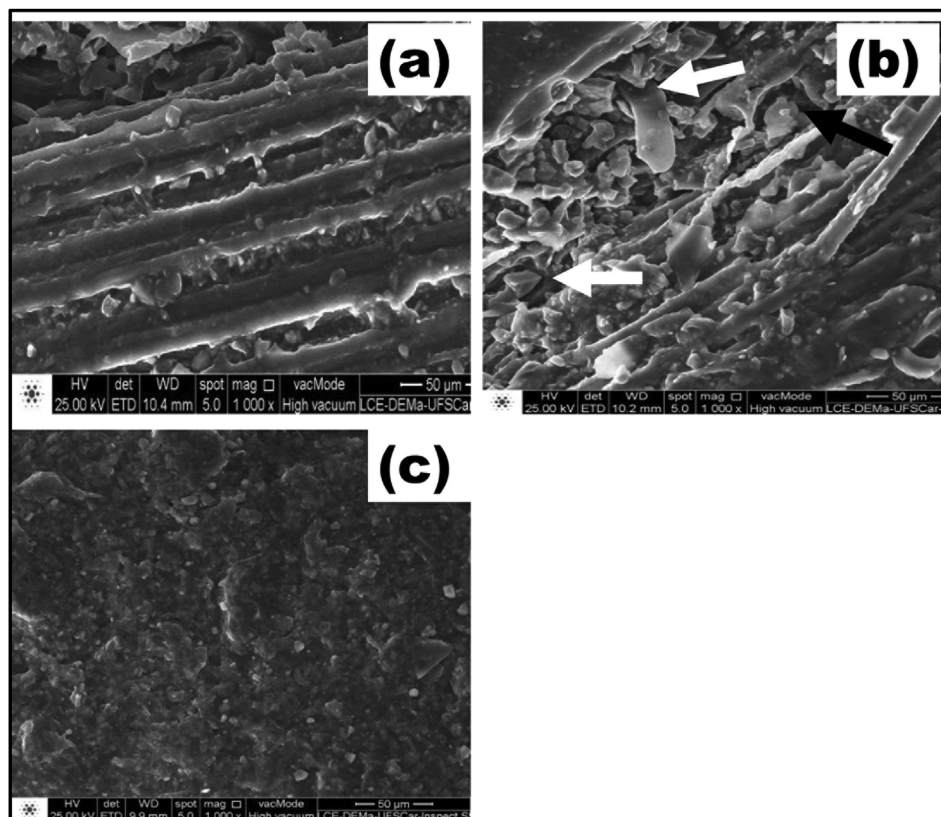


Fig. 9. SEM images of fracture surfaces of (a) hybrid mercerized composite (b) hybrid non-mercerized composite (c) unreinforced polypropylene.

- component samples and the control. This implied that the hybridization created favorable synergy between the two reinforcements to produce enhanced mechanical properties that were superior to that of single-component composites.
- ii. Mercerization treatment was an effective approach for enhancing the crystallinity of BF due to the reduction in lignin and hemicellulose contents, as well as retention of the cellulose constituents of BF. The treatment also aided the development of good interfacial adhesion at the fiber/matrix interface, as observed in the mechanical test results and SEM images.
 - iii. TGA/DTG thermograms and XRD diffractograms confirmed an increase in thermal stability, degradation temperature and crystallinity of the mercerized BF/CaCO₃ hybrid composites.
 - iv. SEM images revealed good interfacial adhesion in the morphology of the mercerized hybrid composite compared to the unmercerized hybrid composite sample.

Data availability

The raw/processed data required to reproduce these findings cannot be shared at this time as the data also forms part of an ongoing study.

References

- [1] A. Moubarik, N. Grimi, N. Boussetta, Structural and thermal characterization of Moroccan sugar cane bagasse cellulose fibers and their applications as a reinforcing agent in low density polyethylene, *Compos. B Eng.* 52 (2013) 233–238, <https://doi.org/10.1016/j.compositesb.2013.04.040>.
- [2] S.M. Luz, A. Caldeira-pires, P.M.C. Ferrão, Resources, conservation and recycling environmental benefits of substituting talc by sugarcane bagasse fibers as reinforcement in polypropylene composites: ecodesign and LCA as strategy for automotive components, *Resour. Conserv. Recycl.* 54 (2010) 1135–1144, <https://doi.org/10.1016/j.resconrec.2010.03.009>.
- [3] V. Fiore, G. Di Bella, A. Valenza, The effect of alkaline treatment on mechanical properties of kenaf fibers and their epoxy composites, *Compos. B Eng.* 68 (2015) 14–21, <https://doi.org/10.1016/j.compositesb.2014.08.025>.
- [4] M.Y. Hashim, M.N. Roslan, A.M. Amin, A. Mujahid, A. Zaidi, Mercerization treatment parameter effect on natural fibre reinforced polymer matrix composite: a brief review, *World Acad. Sci. Eng. Technol.* 6 (2012) 1382–1388.
- [5] H. Salmah, A. Romisuhani, H. Akmal, Properties of low-density polyethylene/palm kernel shell composites: effect of polyethylene co-acrylic acid, *J. Thermoplast. Compos. Mater.* 26 (2011) 3–15, <https://doi.org/10.1177/0892705711417028>.
- [6] V. Matějka, Z. Fu, J. Kukutschová, S. Qi, S. Jiang, X. Zhang, R. Yun, M. Vaculík, M. Heliová, Y. Lu, Jute fibers and powderized hazelnut shells as natural fillers in non-asbestos organic non-metallic friction composites, *Mater. Des.* 51 (2013) 847–853, <https://doi.org/10.1016/j.MATDES.2013.04.079>.
- [7] S. Hussein, K. Seong Chun, A. Hadi, R. Ahmad, Effect of filler loading and coconut oil coupling agent on properties of low-density polyethylene and palm kernel shell eco-composites, *J. Vinyl Addit. Technol.* 22 (2016) 200–205, <https://doi.org/10.1002/vnl>.
- [8] A.L. Pang, H. Ismail, A.A. Bakar, Tensile properties, water resistance, and thermal properties of linear low-density polyethylene/polyvinyl alcohol/kenaf composites: effect of 3-(trimethoxysilyl) as a silane coupling agent, *BioResources* 11 (2016) 5889–5904.
- [9] A.A. Singh, S. Palsule, Thermal properties of jute fiber reinforced chemically functionalized high density polyethylene (JF/CF-HDPE) composites developed by Palsule process, *Appl. Polym. Compos.* 2 (2014) 97–108.
- [10] R. Muthuraj, M. Misra, A.K. Mohanty, Biocomposite consisting of miscanthus fiber and biodegradable binary blend matrix: compatibilization and performance evaluation, *RSC Adv.* 7 (2017) 27538–27548, <https://doi.org/10.1039/c6ra27987b>.
- [11] N. Hamour, A. Boukerrou, H. Djidjelli, J. Maigret, J. Beaugrand, Effects of MAPP compatibilization and acetylation treatment followed by hydrothermal aging on polypropylene Alfa fiber composites, *Int. J. Polym. Sci.* 2015 (2015) 1–9.
- [12] L. Yan, N. Chow, X. Yuan, Improving the mechanical properties of natural fibre fabric reinforced epoxy composites by alkali treatment, *J. Reinf. Plast. Compos.* 31 (2012) 425–437, <https://doi.org/10.1177/0731684412439494>.
- [13] M. Jawaaid, H.P.S. Abdul Khalil, A. Hassan, R. Dungani, A. Hadiyane, Effect of jute fibre loading on tensile and dynamic mechanical properties of oil palm epoxy composites, *Compos. B Eng.* 45 (2013) 619–624, <https://doi.org/10.1016/j.compositesb.2012.04.068>.
- [14] A.L. Pang, H. Ismail, A. Abu Bakar, Degradation of linear low-density polyethylene/poly(vinyl alcohol)/kenaf composites, *Iran, Polym. J.* 26 (2017) 703–709, <https://doi.org/10.1007/s13726-017-0555-8>.
- [15] I.O. Oladele, A.D. Akinwekomi, O.G. Agbabiaka, M.O. Oladejo, Influence of bio-degradation on the tensile and wear resistance properties of bio-derived CaCO₃/epoxy composites, *J. Polym. Res.* 26 (2019) 1–9.
- [16] H. Salmah, A. Romisuhani, H. Akmal, Properties of low-density polyethylene/palm kernel shell composites: effect of polyethylene co-acrylic acid, *J. Thermoplast. Compos. Mater.* 26 (2013) 3–15, <https://doi.org/10.1177/0892705711417028>.
- [17] I.O. Oladele, Effect of bagasse fibre reinforcement on the mechanical properties of polyester composites, *J. Assoc. Prof. Eng. Trinidad Tobago.* 42 (2014) 12–15.
- [18] J. Anggono, Á.E. Farkas, A. Bartos, J. Mócsó, H. Purwaningsih, B. Pukánszky, Deformation and failure of sugarcane bagasse reinforced PP, *Eur. Polym. J.* (2018), <https://doi.org/10.1016/j.eurpolymj.2018.12.033>.
- [19] D.R. Mulinari, J.D.P. Cipriano, M.R. Capri, D.R. Mulinari, J.D.P. Cipriano, M.R. Capri, D.R. Mulinari, J. De Paula, M. Rosa, Influence of sugarcane bagasse fibers with modified surface on polypropylene composites, *J. Nat. Fibers* 15 (2018) 174–182, <https://doi.org/10.1080/15440478.2016.1266294>.
- [20] V.S. Candido, A.C.R. da Silva, N.T. Simonassib, F.S. da Luzb, S.N. Monteiro, Toughness of polyester matrix composites reinforced with sugarcane bagasse fibers evaluated by Charpy impact tests, *J. Mater. Res. Technol.* 6 (2017) 334–338, <https://doi.org/10.1016/j.jmrt.2017.06.001>.
- [21] E.M. Fernandes, J.F. Mano, R.L. Reis, Hybrid cork-polymer composites containing sisal fibre: morphology, effect of the fibre treatment on the mechanical properties and tensile failure prediction, *Compos. Struct.* 105 (2013) 153–162, <https://doi.org/10.1016/j.compstruct.2013.05.012>.
- [22] D. Romanzini, A. Lavoratti, H.L. Ornaghi, S.C. Amico, A.J. Zattera, Influence of fiber content on the mechanical and dynamic mechanical properties of glass/ramie polymer composites, *Mater. Des.* 47 (2013) 9–15, <https://doi.org/10.1016/j.matdes.2012.12.029>.
- [23] W. Li, A. Dichiar, J. Bai, Carbon nanotube – graphene nanoplatelet hybrids as high-performance multifunctional reinforcements in epoxy composites, *Compos. Sci. Technol.* 74 (2013) 221–227, <https://doi.org/10.1016/j.compscitech.2012.11.015>.
- [24] S. Salma, M. Fayeka, H. Mahbub, H. Azman, Effect of reinforcement and chemical treatment on the properties of jute-coir fiber reinforced hybrid polypropylene composites, *Fibers Polym.* 15 (2014) 1023–1028.
- [25] J.G. Gummati, V. Kumar, G. Rajesh, Evaluation of flexural properties of fly ash filled poly-propylene composites, *Int. J. Mod. Eng. Res.* 2 (2012) 2584–2590.
- [26] Y.W. Leong, Z.A. Mohd, A. Ariffin, Mechanical and thermal properties of talc and calcium carbonate filled polypropylene hybrid composites, *J. Appl. Polym. Sci.* 91 (2004) 3327–3336.
- [27] E. Părpăriță, R.N. Darie, C.M. Popescu, M.A. Uddin, C. Vasile, Structure-morphology-mechanical properties relationship of some polypropylene/lignocellulosic composites, *Mater. Des.* 56 (2014) 763–772, <https://doi.org/10.1016/j.matdes.2013.12.033>.
- [28] M. Cai, H. Takagi, A.N. Nakagaito, Y. Li, G.I.N. Waterhouse, Effect of alkali treatment on interfacial bonding in abaca fiber-reinforced composites, *Compos. Part A* 90 (2016) 589–597, <https://doi.org/10.1016/j.compositesa.2016.08.025>.