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Banana fibers and microfibrils as lignocellulosic reinforcements in polymer composites

Maha M. Ibrahim[a], Alain Dufresne[b], Waleed K. El-Zawawy[a,*], Foster A. Agblevor[c]

[a] Cellulose and Paper Department, National Research Center, El-Tahrir St., Giza, Egypt
[b] Grenoble Institute of Technology (INP) - The International School of Paper, Print Media and Biomaterials (PAGORA), BP 65, 38402 Saint Martin d'Hères Cédex, Grenoble, France
[c] Department of Biological Systems Engineering, Virginia PolyTechnic Institute and State University, Blacksburg, VA, USA

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ABSTRACT

Banana plant waste, as lignocellulosic fiber, was treated with alkaline pulping and steam explosion to produce banana fibers and banana microfibrils. The chemical composition of the ensuing fibers and microfibrils was determined. The chemical modification, with maleic anhydride, of the produced particles was further carried out. The FT-IR analysis and scanning electron microscopy observations of the resulting modified and unmodified banana fibers were investigated. Composite materials were processed from these natural unmodified and maleated lignocellulosic fibers using polyethylene as the polymeric matrix. The thermal and mechanical properties were studied by differential scanning calorimetry (DSC) and tensile tests, respectively. The morphology of processed composites was studied by scanning electronic microscopy (SEM). Better compatibility and enhanced mechanical properties were obtained when using banana microfibrils. The chemical composition of fibers, in terms of lignin and cellulose, as well as their degree of crystallinity, were found to have a strong influence on the mechanical properties of the composites.

1. Introduction

It is well known that over the past few decades, polymers have replaced many conventional materials in various applications, which is obviously due to the advantages of polymers over conventional materials (Georgopoulos, Tarantili, Avgerinos, Andreopoulos, & Koukios, 2005). Polymers can be modified by the use of fillers and reinforcing fibers to suit the high strength/high modulus requirements. Fiber-reinforced polymers offer additional options over other conventional materials when specific properties are required and find applications in diverse fields, ranging from appliances to spacecraft (Nabi Saheb & Jog, 1999).

Natural fiber is a reinforcement which has recently attracted the attention of researchers because of its advantages over the other established materials (Bledzki & Gassan, 1999; Nabi Saheb & Jog, 1999). Natural fibers are composed of various organic materials (primarily cellulose, as well as hemicelluloses and lignin) and therefore their thermal treatment leads to a variety of physical and chemical changes (Georgopoulos et al., 2005).

The strength of short-fiber-reinforced composites is highly dependent on the degree of interfacial adhesion, whereas the modulus is controlled by the fiber orientation (Maldas & Kokta, 1993). An important factor which influences the fracture properties is the aspect ratio. In short-fiber-reinforced composites, a critical length of the fiber is required to develop its fully stressed condition in the polymer matrix (Nabi Saheb & Jog, 1999). An improved combination of fiber and polymer is achieved by impregnation of fibers with polymers compatible with the matrix. An effective method of chemical modification of natural fibers is graft co-polymerization. The resulting co-polymer displays the characteristic properties of both fibrous cellulose and grafted polymer (Dale Ellis & O'Dell, 1999; Patil, Gajre, Dusane, Chavan, & Mishra, 2000).

In an effort to improve the mechanical properties of recycled high-density polyethylene/wood fiber (HDPE/wood) composites, Selke, Yam, and Nieman (1989) investigated the use of several additives with possible effect on the fibers/matrix adhesion or fibers dispersion into the matrix. They found that maleic anhydride modified polypropylene appears especially promising, since its use at a concentration of 5% in composites with 30% wood fibers results in an increase in tensile strength and elongation at break. Similar results were found in the study of Dalvag, Klason, and Strom vall (1985), who also reported that the composites's elastic modulus remained unchanged.

In the recent years, an increased interest in obtaining composite materials with organic micro (nano) reinforcement has been observed. This can be explained by the extraordinary properties induced in polymers by the nano-metric size reinforcement and by the favorable effects on the environment (Panaitescu et al., 2007).

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* Corresponding author.
E-mail address: wkzawawy@yahoo.com (W.K. El-Zawawy).

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Cellulose microfibrils with diameters of 50–5000 nm have already been prepared (Chakraborty, Sain, & Kortschot, 2005; Nakagaito & Yano, 2004). Cellulose microfibrils with micron and submicron diameters were prepared by mechanical treatment of pulp fibers and were used for micro (nano) composites preparation (Nakagaito, Iwamoto, & Yano, 2005). The great advantage of using cellulose microfibrils for polymers reinforcement arises from the remarkable mechanical properties of such fibers. However, cellulose microfibrils do not develop in polymer composites their reinforcement capacity because of poor adhesion to common non-polar matrices (Panaitescu et al., 2007). The presence of absorbed water and hydroxyl groups reduces the ability of cellulose microfibrils to develop good interface adhesion to most polymer matrices (Laka & Chernyavskaya, 1996). To avoid these drawbacks, cellulose microfibrils can be submitted to specific surface modifications by physical, physicochemical, or chemical treatments (Laka & Chernyavskaya, 1996; Maskavs, Kalnins, Laka, & Chernyavskaya, 2001).

In a previous work (Habibi, El-Zawawy, Ibrahim, & Dufresne, 2008), cotton stalk, rice straw, bagasse and banana were used without modification as fiber reinforcement. The results indicate that for better polymer–fiber bond we have to use a modified polymer in the presence of a compatibilizer. In the present work, a decision was made to modify the lignocellulosic fibers in a trial to match a good fiber–polymer bond without addition of a compatibilizer. According to that, polymer composites from polyethylene (PE) and two types of lignocellulosic fibers from waste biomass were prepared and characterized. Banana plant waste, as the biomass material, was treated chemically and physicochemically, by alkaline pulping and steam explosion, to produce lignocellulosic fibers (BF) and lignocellulosic microfibrils (BMF). To enhance the compatibility of the produced fibers and microfibrils with the PE matrix, chemical modification for the alkaline pulping banana and steam-exploded banana were carried out with maleic anhydride (MA). The efficiency in PE composites with various concentrations of banana fibers (BF) and microfibrils (BMF) was investigated by morphostructural and physicomechanical characterization.

2. Experimental

2.1. Materials and chemicals

Commercial high-density polyethylene (PE) (density 0.922 g/cm^3) was used as the polymer matrix. Maleic anhydride (MA) was purchased from s.d. Fine-Chem Ltd., and xylene was purchased from Surechera Products Ltd. (UK). All materials were used without further purification.

Banana plant waste was used as the biomass raw material source for the natural lignocellulosic fibers. It was pulped with 10% sodium hydroxide (NaOH) to produce banana fiber (BF) and steam exploded to produce banana microfibrils (BMF). The fibers and microfibrils used in this study were chemically characterized for holocellulose (TAPPI T257 om-85), Klason lignin (TAPPI T222 om-88) and ash content (TAPPI T211 om-85).

2.2. Fiber preparation

2.2.1. Pulping

Banana fiber (BF) was prepared applying the alkaline pulping process. The pulp was prepared from the banana plant waste on an electrically heated rotatory autoclave. The pulping conditions were as follows: total chemicals as NaOH was 10% (w/w), and liquor to fiber ratio was 10:1. The cooking cycle employed at (a) time from room temperature to 170 °C was 1 h, and (b) time for cooking at 170 °C was 2 h.

2.2.2. Steam explosion

Steam explosion technology involves treating various biomass feedstocks with saturated steam at various reaction times. In steam explosion the biomass is pressurized with steam for a short time and then explosively discharging the product to atmospheric pressure, which results in a sudden decomposition. This explosive discharge changes the starting material (solid) into fibrous mulch producing cellulosic microfibrils.

Steam explosion of the banana plant waste (BPW) sample was carried out in a 25-l batch reactor located at the Thomas M. Books Forest Products Center, Blacksburg, VA. The procedure reported by Jeoh & Agbelvor (2001) was used in this study. About 1 kg of BPW sample was weighed and loaded into a 25-l batch steam explosion chamber and the ball valve was closed. Saturated steam was admitted into the chamber and the biomass temperature was raised to 220 °C. When the material attained the reaction temperature, timing of the reaction was started. For this experiment, 240 s was used for the reaction. After 240 s, the release valve was opened which caused a rapid reduction in pressure, explosive decomposition and disintegration of the biomass material. The steam explosion chamber was washed with water to recover any residual fiber trapped in the unit. The sample was bagged and stored in a cold room until the time of polymer composite preparation.

2.3. Preparation of maleated lignocellulosic fibers

The modification of BF resulting from pulping and BMF resulting from steam explosion was conducted in a round flask in the presence of a solvent. The reaction procedure used for synthesizing maleated lignocellulosic fiber and microfibrils was as follows: 250 ml of solvent (xylene) was placed in a 500 ml round flask fixed with a condenser and stirred to 100 °C. After reaching this temperature, 67–70 g of MA, 3 g of either BF, or BMF, and 1 g of sodium hypophosphite monohydrate were placed in the flask. The reaction was carried out for 2 h at 100 °C. After the reaction, the mixture was filtered to isolate the reacted BF and BMF, subjected to Soxhlet extraction with xylene for 24 h to remove the unreacted anhydride, and oven dried at 70 °C for 24 h. The reaction product thus obtained was characterized by FT-IR and scanning electron microscopy (SEM).

2.4. Composites preparation

The incorporation of lignocellulosic fibers and maleated fibers into the PE was carried out thorough mixing at high temperature, in xylene, for sufficient time to achieve the maximum possible dispersion. PE was first soluble in 10% (w/v) xylene at high temperature then the fibers were mixed with the soluble polymer with stirring until homogeneity. After mixing, the samples were left to cool at room temperature and left overnight to solidify then put into a steel mould and left for 5 min in the hydraulic press, preheated at 130 °C to form films of ~0.6 mm thickness.

2.5. Characterization and properties

2.5.1. FT-IR spectra

FT-IR spectroscopy was used to confirm whether an esterification reaction occurred between BF and/or BMF and MA. Also, it was used to access the crystallinity index of the fiber and the maleated fiber according to O'Connor, DuPré, and Mitcham (1958), which is based on the ratio of the absorbance of the bands at 1429 (CH_2 scissoring) and 893 cm^{-1} ($C_{(1)}$ group vibration).

The IR spectra of BF, BMF, maleated banana fiber (M-BF) and maleated banana microfibrils (M-BMF) were performed using a Thermo-Nicolet Model 670 Instrument (Thermo Electron, Inc., Madison, WI). The result of FT-IR spectrum of MA was taken from

Table 1
Chemical analysis, crystallinity index and geometrical characteristics of banana microfibrils resulting from the steam explosion of the banana plant waste (BMF) and banana fibers resulting from the alkaline pulping of the banana plant waste with 10% NaOH (BF).

Unbleached banana fibers	Holocellulose (%)	Lignin (%)	Ash (%)	Crystallinity index	Diameter (μm)	Length (μm)	Aspect ratio (*l*/*d*)
BMF	52.76	23.22	19.02	1.75	8.25	35.96	4.36
BF	82.1	8.50	9.60	1.25	13.16	175.2	13.31

the literature (Kazayawoko, Balatinecz, & Woodhams, 1997) and was obtained with a Bruker FT-IR unit, Model IFS 85.

2.5.2. Scanning electron microscopy

Scanning electron microscopy (SEM) was used to investigate the morphology of the different types of materials, i.e. BF, BMF, M-BF and M-BMF, and the filler/matrix interface by using a JEOL JXA-840 A electron microprobe analyzer (JEOL USA Inc., Peabody, MA). The specimens for the polymer composites were frozen under liquid nitrogen, fractured, mounted, coated with gold/palladium and observed using an applied tension of 30 kV.

2.5.3. differential scanning calorimetry (DSC)

DSC experiments were performed using a DSC Q100 differential scanning calorimeter (TA Instruments, USA), where the samples of the polymer composites were heated from 40 to 200 °C at a heating rate of 10 °C/min. The melting temperature T_m was taken as the peak temperature of the melting endotherm.

2.5.4. Tensile tests

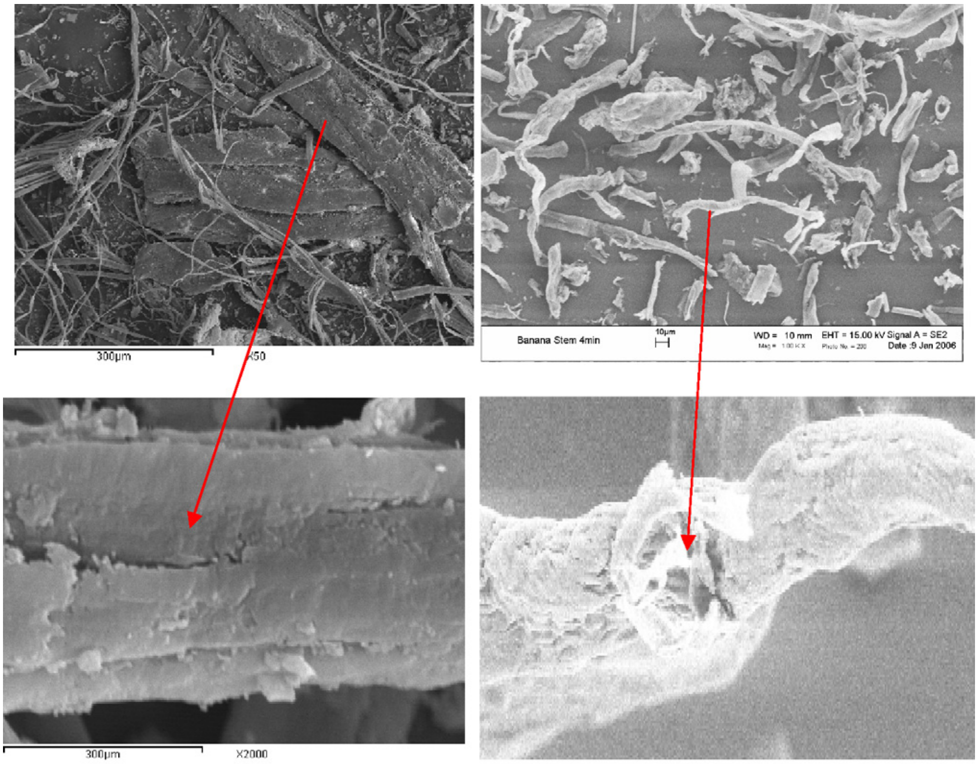
The mechanical behavior of the composites prepared with different fibers was analyzed with a LLOYD Instrument, Model LR 10K with a load cell of 1000 N. Experiments were performed with a crosshead speed and distance between jaws of 5 mm/min and 50 mm, respectively, at room temperature, 25 °C. The dimensions of the test samples were: length 100 mm, width 16.5 mm and thickness below 1.0 mm. Young's modulus and tensile strength were calculated on the basis of initial sample dimensions, and the results were averaged over five measurements.

3. Results and discussion

3.1. Fibers characterization

The chemical characterization revealed the proportion of each component of the fibers from agricultural residues. Results are collected in Table 1 and indicated much lower hollocellulose content for the BMF compared to BF. It is ascribed to the degradation of the amorphous part of the cellulose during the steam explosion process which can be noticed from the SEM observation of alkaline and steam-exploded banana fibers in Fig. 1. A closer look at the microfibril surface of the steam-exploded banana fibers at higher magnification shows that many terraces, steps, and holes form by the explosion technology. We propose that these changes result from the removal of very reactive amorphous cellulose from the surface. In addition, the steam explosion process induces a re-condensation of the lignin onto the fibers as shown from the higher lignin content for BMF (Table 1), and hence a higher ash content. During the alkaline pulping, the lignin dissolved and separated in the black liquor.

Moreover, the SEM images obtained for these samples revealed the distribution of fiber diameters. The average diameter for the BMF resulting from the steam explosion was 8.25 μm, while it was



Banana alkaline pulp

Steam exploded banana

Fig. 1. SEM for alkaline pulping banana and steam-exploded banana.

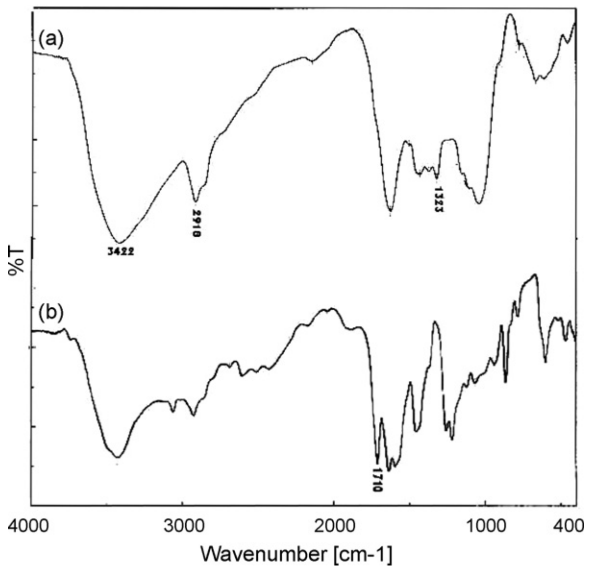


Fig. 2. FT-IR for (a) BF and (b) M-BF.

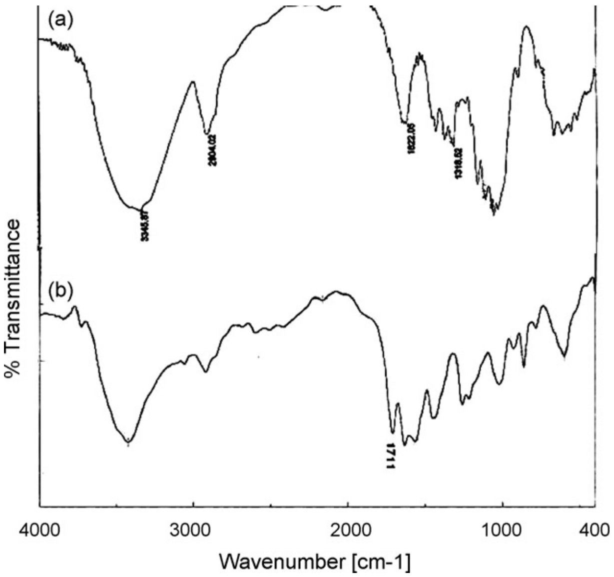


Fig. 3. FT-IR for (a) BMF and (b) M-BMF.

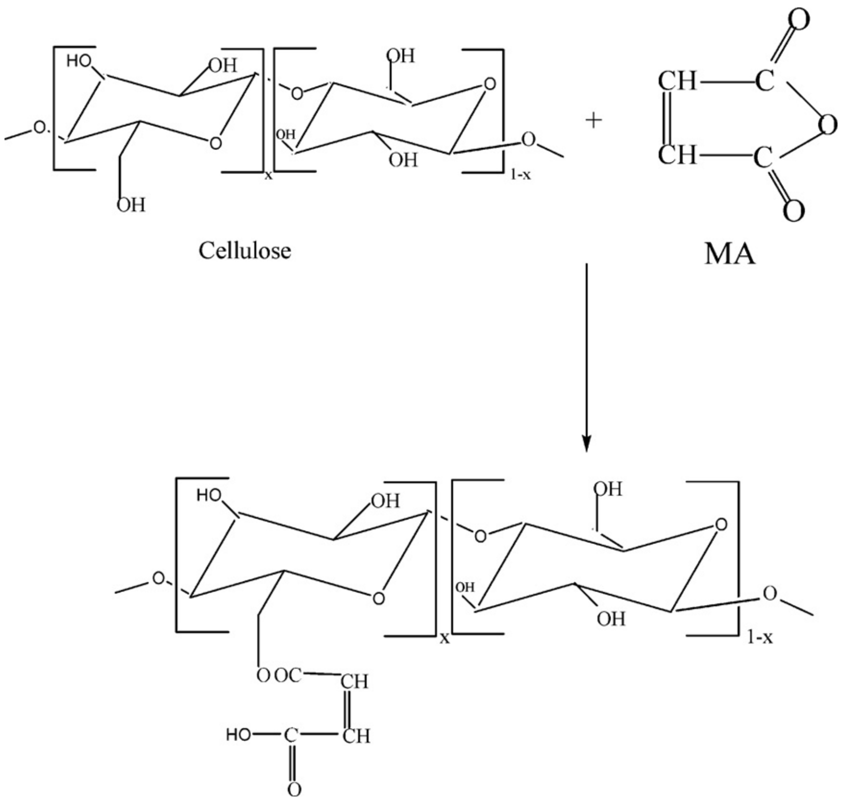
13.16 μm for BF resulting from alkaline pulping (Table 1). Also, the length of the fibers decreased upon steam explosion treatment, and hence the aspect ratio *l*/*d* for BF was 13.31 and it was significantly higher than the *l*/*d* of BMF, 4.36 (Table 1).

The changes in cellulose structure induced by the different treatments were also corroborated by other physicochemical properties, such as the crystallinity index. The results indicated that the crystallinity index for the BMF resulting from the steam explosion of the banana is higher than for the BF resulting from the alkaline pulping of the banana (Table 1). This can be attributed to the partial removal of the amorphous cellulose domains induced by the steam explosion treatment and hence to the ensuing increase of the degree of crystallinity.

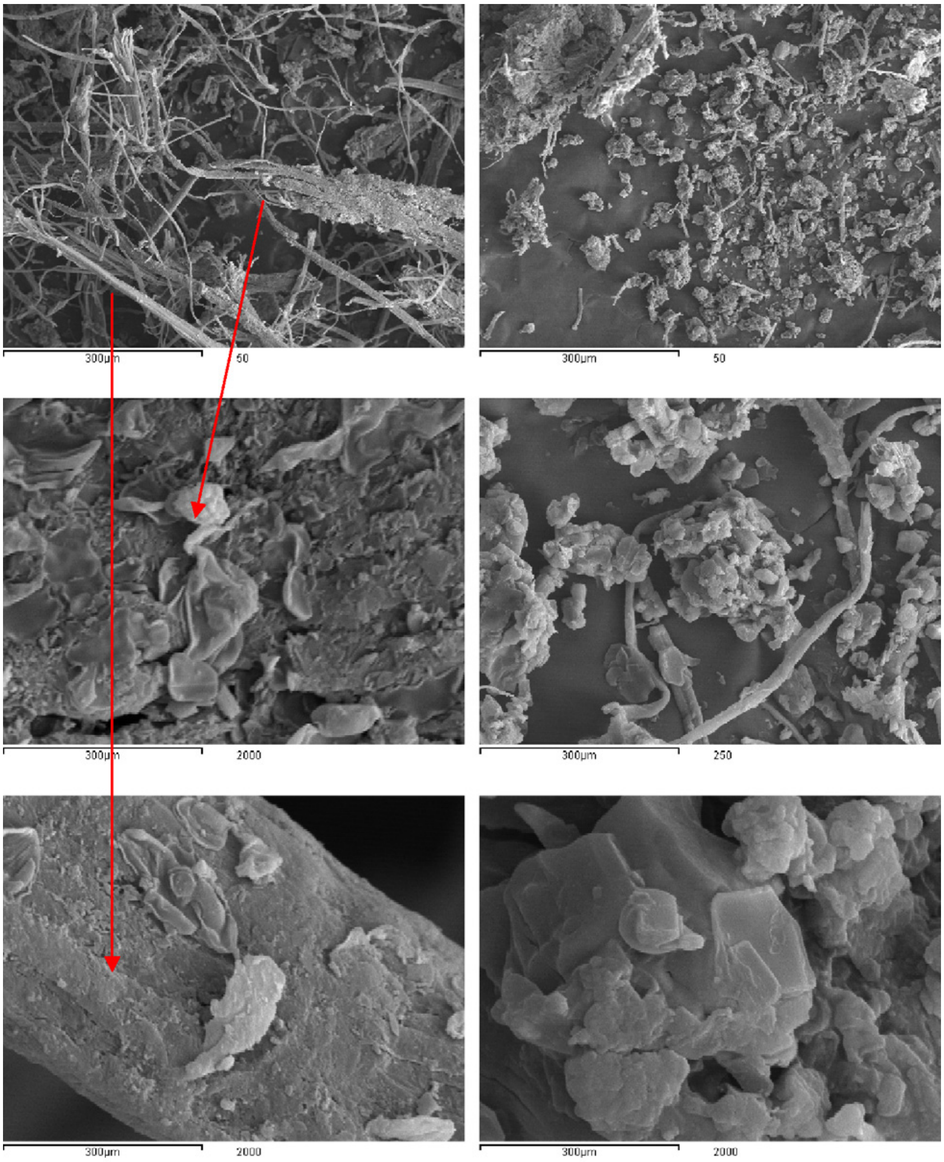
3.2. Characterization of maleated fiber and microfibers

3.2.1. FT-IR spectra

Figs. 2(a) and 3(a) show the absorption spectra of untreated BF and BMF, respectively, in the 4000–400 cm^{-1} region. The absorption band at 3422 and 3345 cm^{-1}, for BF and BMF, respectively, may be due to various hydroxyl (OH) stretching vibrations. The OH compounds may include absorbed water, aliphatic primary



Scheme 1. Reaction between cellulose and maleic anhydride.



Maleated alkaline banana pulp (M-BF) maleated steam exploded banana (M-BMF)

Fig. 4. SEM for maleated banana fiber (M-BF) and maleated banana microfibrils (M-BMF).

and secondary alcohols found in cellulose, hemicellulose, lignin, extractives; and carboxylic acids in extractives (Khan, Idriss Ali, & Basu, 1993; Kolboe & Ellefsen, 1962). The absorption band near the OH stretching vibrations, at 2918 and 2904 cm^{-1} for BF and BMF, respectively, may be associated to CH stretching vibrations. Kolboe and Ellefsen (1962) suggested that the bands in the 1644 cm^{-1} region for cellulose may be attributed to C=O stretching vibration of the alpha-keto carbonyl. The presence of the bands at 1323 and 1318 cm^{-1}, for BF and BMF, respectively, may be attributed to the lignin (syringic group). According to the literature (Ibrahim, 2000), the peaks at 1170–1040 cm^{-1} arise from the ether linkage.

Figs. 2(b) and 3(b) represent the FT-IR spectra for maleic anhydride treated BF and BMF, respectively. According to the literature (Kazayawoko et al., 1997), pure MA contains a large number of bands. It was mentioned that the appearance of bands in the 3100–2600 cm^{-1} region are due to the CH stretching vibrations of CH_2. The anhydride carbonyl symmetric and asymmetric stretching vibrations are characterized by absorption bands in the 1870–1770 cm^{-1} region. The bands near 1710 cm^{-1} may be ascribed to carboxyl groups present in maleic anhydride. The bands in the 1400–1300 cm^{-1} region are due to the CH deformation vibrations of CH_2, while the bands in the 1200–1000 cm^{-1} region may possibly be due to the CH rocking vibrations of CH_2, and also to C–C stretching vibrations.

The esterification of BF and BMF with MA was studied. Since the ester function groups absorb in the 1750–1720 cm^{-1} region, the following discussion will focus on that region. Figs. 2 and 3 show the FT-IR spectra of both untreated BF and BMF, as well as M-BF and M-BMF. As may be seen from the comparison of the FT-IR spectra, there is an emergence of a new and well-defined absorption band at 1710 and 1711 cm^{-1}, for M-BF and M-BMF, respectively. It may be attributed to carbonyl stretching vibrations of carboxyl groups present in the maleated product. The presence of this band is therefore attributed to the esterification reaction between hydroxyl groups of both BF and BMF and anhydride groups of MA as presented in Scheme 1.

3.2.2. SEM of maleated BF and BMF

The morphological structure for the modified alkaline-pulped and steam-exploded banana were studied. Fig. 4 illustrated the

Table 2
Melting temperature (T_m) of PE-based composites reinforced with lignocellulosic fibers, unmodified and modified, using data obtained from the DSC curves.

Sample	Fiber content (wt%)	T_m (°C)
PE	0	133.4
	20	131.3
BF[a]	40	132.5
	60	130.9
	20	133.4
BMF[b]	40	132.3
	60	132.4
	20	132.0
M-BF[c]	40	131.7
	60	131.8
	20	134.4
M-BMF[d]	40	132.1
	60	132.9

[a] BF: banana fiber from alkaline-pulped banana.
[b] BMF: banana microfibrils from steam-exploded banana.
[c] M-BF: maleated banana fiber.
[d] M-BMF: maleated banana microfibrils.

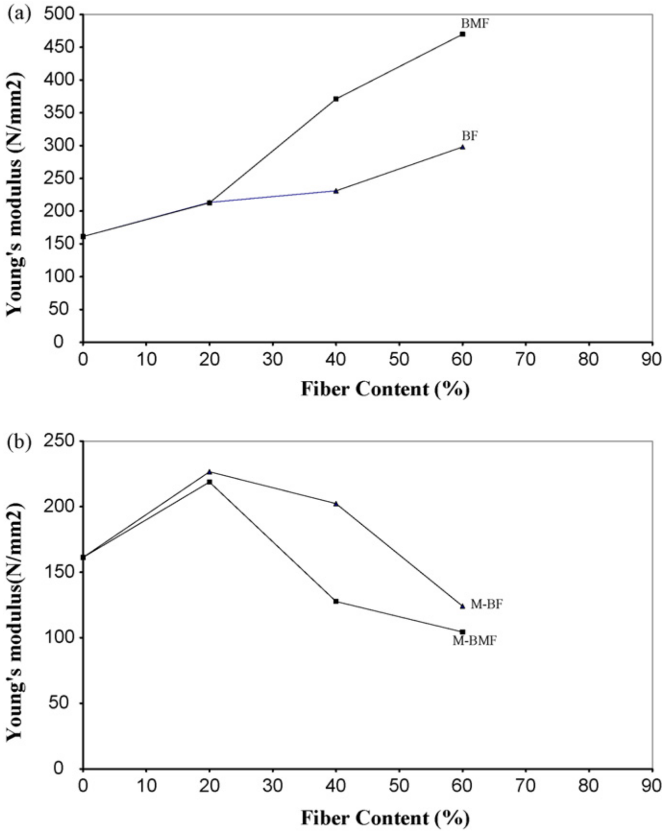


Fig. 5. Young's Modulus versus fiber content for (a) PE-BF and PE-BMF, and (b) PE-M-BF and PE-M-BMF composites.

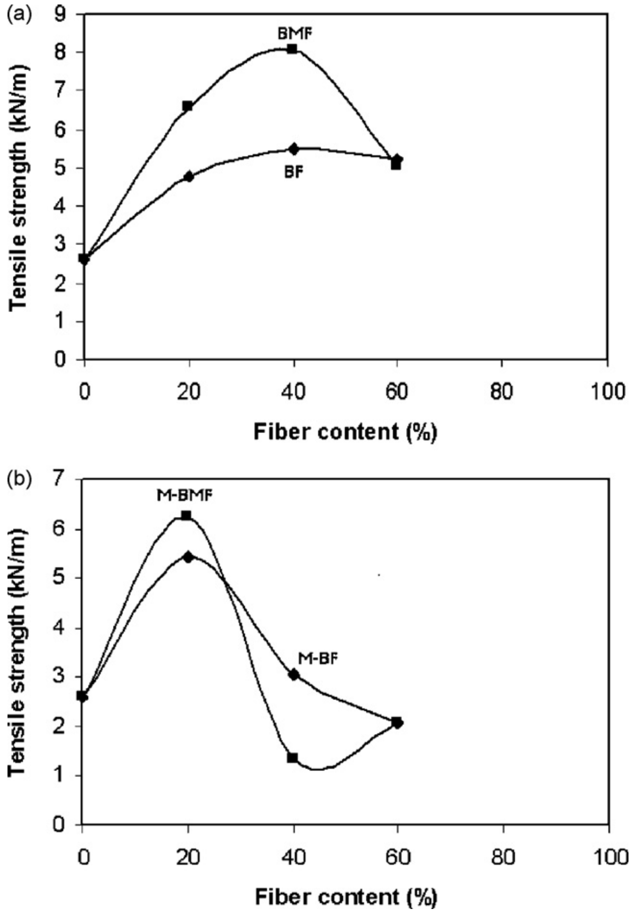


Fig. 6. Tensile strength versus fiber content for (a) PE-BF and PE-BMF, and (b) PE-M-BF and PE-M-BMF composites.

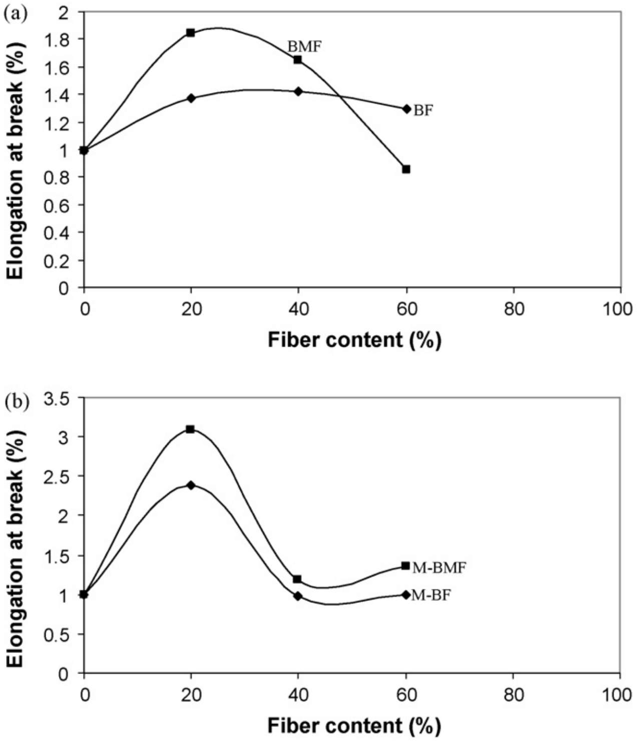
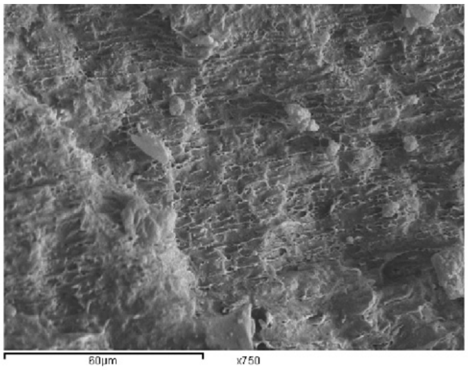
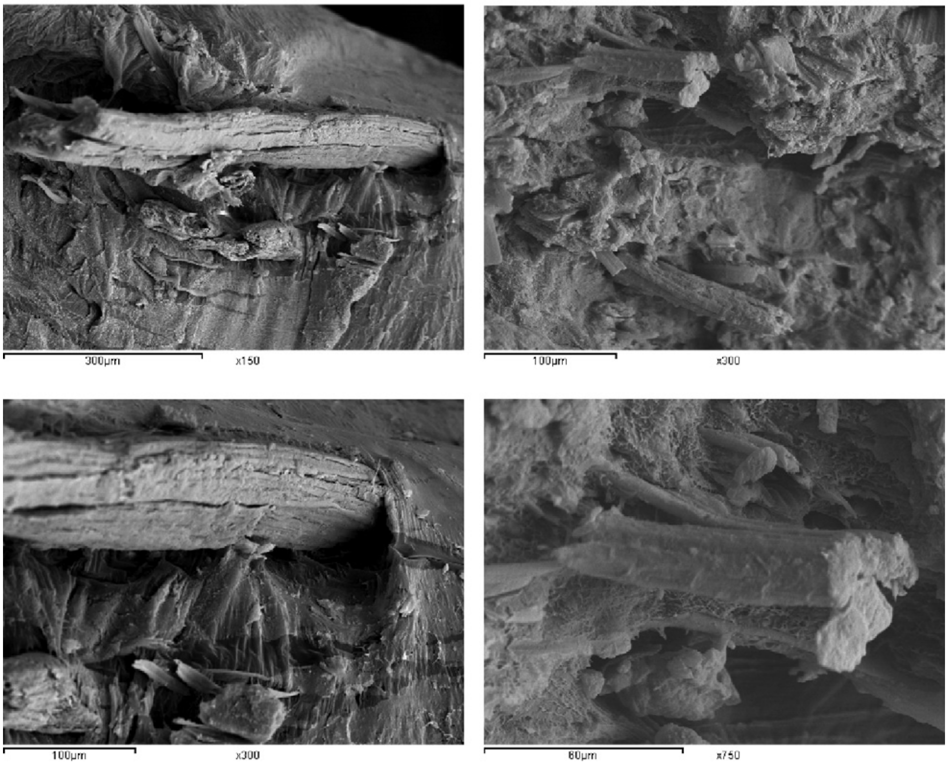


Fig. 7. Elongation at break versus fiber content for (a) PE-BF and PE-BMF, and (b) PE-M-BF and PE-M-BMF composites.

SEM for the maleated banana fibers and microfibrils, which showed different morphological structures between the maleated banana fiber (M-BF) resulting from the modification of alkaline-pulped banana and maleated banana microfibrils (M-BMF) resulting from the modification of steam-exploded banana. The treatment with MA results in a dramatic reduction of the particle size for the steam-exploded banana compared to the pulped banana, 2.75 and 5.5 μm, respectively (Fig. 4).



PE



40% BF-PE 40% BMF-PE

Fig. 8. SEM for 40% BF and BMF with the PE.

3.3. *Characterization of PE-lignocellulosic composites*

3.3.1. *Thermal analysis*

The melting characteristics of PE-based composites reinforced with BF, BMF, M-BF and M-BMF obtained from DSC analysis are presented in Table 2. The melting of the unfilled PE revealed an endothermic event with an endothermic peak centered at 133 °C. A two-step melting was observed (diagram not shown). The reason for a two-step melting could be melt recrystallization during the heating rate, secondary nucleation of crystals in polymer materials caused by impurities or induced by a dual population of crystallite sizes. The appearance of the two-step melting peaks may overcome by changing the DSC program by applying heating, cooling then reheating again. Because of this complex endothermal peak, the degree of crystallinity of the samples was not determined. The addition of the fibers or maleated fibers in PE did not change significantly the melting temperature. However, it is observed that the addition of banana fibers obtained by alkaline pulping (BF and M-BF) tend to slightly decrease the melting point compared to the neat matrix and microfibrils reinforced composites.

3.3.2. *Mechanical properties of PE composites*

Raj, Kokta, Dembele, and Sanschagrain (1989) investigated the influence of using various dispersing aids (stearic acid and mineral oil) and a coupling agent (maleated ethylene) in cellulose fiber-reinforced polypropylene composites. They came to the conclusion that the chemical bonding between the anhydride and the hydroxyl groups caused a better stress transfer from the matrix to the fibers, leading to a higher tensile strength.

In the present study, composite materials were prepared using PE as matrix. For PE-based composites, BF, BMF, M-BF and M-BMF were used as fiber reinforcement. The evolution of the mechanical properties, viz. Young's modulus and tensile strength, as a function of the fiber content are shown in Figs. 5 and 6, respectively. The Young's modulus for unmodified BMF reinforced composites was found to be higher compared to unmodified BF-based composite

(Fig. 5a) which may be a consequence of the higher degree of crystallinity of BMF compared to BF, 1.75–1.25, respectively (Table 1), while the Young's modulus decreases for both M-BF and M-BMF reinforced composites due to the decrease in their degree of crystallinity (crystallinity index for both is 1.0).

On the other hand, the strength (Fig. 6) clearly increased as the fiber content increased in case of unmodified BF and BMF, except for the addition of 60 wt% of fibers. In contrast it tends to decrease upon the addition of 20 wt% of maleated fibers in both the cases of M-BF and M-BMF. These results show that the addition of 20% maleated fiber results in a better adhesion between the filler and the matrix compared to the untreated fiber and thus a better stress transfer from the matrix to the filler. This can be ascribed to the reduction of the particle size for the maleated fibers as reported from SEM observations (Fig. 4). It was mentioned by Fua, Fengb, Laukec, and Maid (2008) that the mechanical properties of particulate–polymer composites depend strongly on the particle size, particle–matrix interface adhesion and particle loading. For the particle size, it has an obvious effect on the mechanical properties (Fua et al., 2008). Stiffness or Young's modulus can be readily improved by adding either micro- or nano-particles (Fu & Lauke, 1998; Wang, Berry, Braden, & Bonfield, 1998; Zhu, Yang, Yin, & Qi, 1999). Young's modulus is the stiffness (the ratio between stress and strain) of a material at the elastic stage of a tensile test. It is markedly improved by adding micro- and nano-particles to a polymer matrix since hard particles have much higher stiffness values than the matrix.

On the other hand, the strength of a material is defined as the maximum stress that the material can sustain under uniaxial tensile loading. For micro- and nano-particulate composites this relies on the effectiveness of stress transfer between matrix and fillers. However, strength strongly depends on the stress transfer between the particles and the matrix. For well-bonded particles, the applied stress can be effectively transferred to the particles from the matrix (Hsueh, 1987); this clearly improves the strength (Ou, Yang, & Yu, 1998; Zhu et al., 1999). However, for poorly bonded micro-particles, strength reductions occur by adding particles (Fu & Lauke, 1998; Liang, Li, & Tjong, 1997). Moreover, Pukanszky and Voros (1993) mentioned it clearly that for a given particulate volume fraction, the composite strength increases with decreasing particle size. Smaller particles have a higher total surface area for a given particle loading. This indicates that the strength increases with increasing surface area of the filled particles through a more efficient stress transfer mechanism. To conclude, particle size clearly has a significant effect on the strength of particulate-filled polymer composites, which generally increases with decreasing size.

The elongation at break of the material increased in the presence of the fiber and the maleated fibers for low content level, as can be seen from Fig. 7. At high filling level, it decreases. It can be noticed that the BMF and the M-BMF have the highest elongation at break compared to the BF and M-BF. Furthermore, higher tensile strength is obtained when using BMF instead of BF. One possible explanation, as derived from Table 1, is that BMF has the highest lignin content, which could probably act as a natural lubricant facilitating the fiber dispersion within the polymer matrix. Other explanation for improving the strength can be derived from the fact that lignin can be act as compatibilizing agent in PE blends (Aradoaei, Darie, Constantinescu, Olariu, & Ciobanu, 2010; Pucciariello, Villani, Bonini, D'Auria, & Vetere, 2004).

The fracture surfaces for the 40 wt% lignocellulosic filler reinforced composites were examined using SEM for both BF and BMF. Other composites were examined as well (i.e. 20 and 60 wt% fibers contents), but the results were found to be most apparent for the 40 wt% fiber content level. Whereas a rather smooth fracture surface was seen for unfilled PE, fiber pull out as well as holes, especially for BF, resulting from fiber delamination were observed for the composites reinforced with unmodified fibers

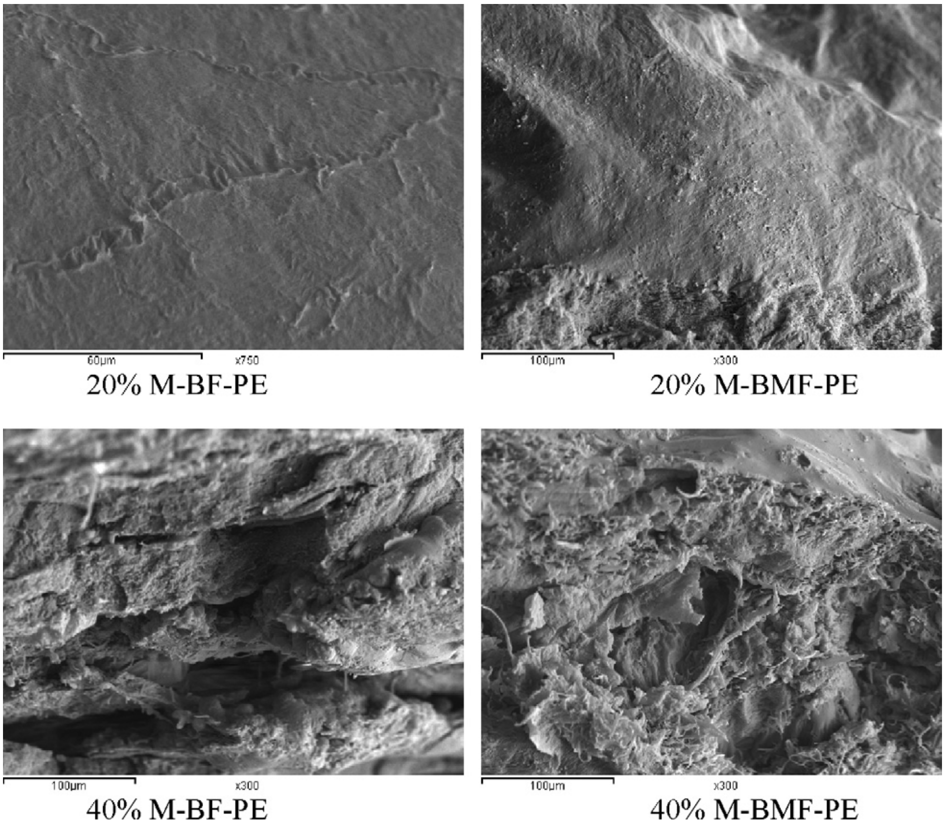


Fig. 9. SEM for 20 and 40% M-BF and M-BMF with the PE.

(Fig. 8). Normally, pulled-out fibers and gaps in the interfacial zone are observed when the adhesion between the fibers and the matrix is not sufficient, and this suggests poor fiber–matrix compatibility. In contrast to unmodified fiber–PE composites, maleated fibers (20 wt%) in PE-based composites were found to be coated by the matrix (Fig. 9). This indicates that the fibers are more compatible with the PE matrix and a continuum between both components is observed. No pull-out of the fibers was observed. The same observations were reported for the composite materials reinforced with 40 wt% fibers, but with a starting of the formation of holes, which lead to a decrease in the adhesion between the maleated fibers and the PE matrix and hence a decrease in the tensile strength.

4. Summary and conclusion

Lignocellulosic fillers extracted from banana plant waste were prepared from either an alkaline pulping treatment or steam explosion. They were used to reinforce a polyethylene matrix. With maleic anhydride, the particle size was reduced for the steam-exploded banana fiber compared to the alkaline-pulped banana fiber. The addition of 20% maleated fiber results in a better adhesion with the polymer matrix, and thus better tensile strength, while for further fiber concentration it seems to lose its flexibility and lead to poor adhesion with the polymer matrix. It can be assumed that the increased phase adhesion results in better properties no matter of the lower particle size. In addition, it was shown that the higher crystallinity of the steam-exploded banana fiber results in a higher modulus, and also the higher lignin content for the steam-exploded banana fiber facilitate the fiber dispersion into the polymer matrix and results in a higher tensile strength and a higher degree of crystallinity to the resulted composite.

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