Preparation and Characterization of Lemongrass Fiber (*Cymbopogon* species) for Reinforcing Application in Thermoplastic Composites

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Lemongrass fiber was analyzed to determine the chemical proportion of its lignocellulosic components. Fibers' thermal behavior, surface structures, and functionality were assessed by thermogravimetric analysis (TGA), scanning electron microscope (SEM), and Fourier transform-infrared spectroscopy (FT-IR), respectively. High-density polyethylene (HDPE) matrix composites filled with varying (10%, 20%, 30%, 40%, and 50%) fiber content were prepared and investigated. Composite wicker was made from HDPE and low density polyethylene (LDPE) blend-matrix and 10% alkaline modified fiber. Alkaline or maleic anhydride grafted polypropylene (MA-g-PP) was used to improve the compatibility between the fiber and matrices. The composites were evaluated by using TGA, SEM microscopy, and universal testing machine, respectively. The fiber was constituted by equitable amounts of lignocellulosic components with cellulose accounting for the highest proportion. It also exhibited high degradation temperature, which was further increased following alkaline modification. Superior thermal degradation behavior was measured for modified fiber composites. SEM showed that the modified fiber composites demonstrated better compatibility. Lemongrass fiber reinforcement substantially improved the mechanical properties of the composites.

Key words: Lemongrass fiber; HDPE; Mechanical properties; Physical properties

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INTRODUCTION

An increased interest in ecofriendly and biodegradable materials is the driving force for the use of natural fibers as reinforcement in polymer matrix composite materials. Reinforced natural fibers or filled composite materials have emerged as high performance materials with economic and environmental advantages (Rout *et al.* 2001; Abdelmouleh *et al.* 2005; Mominul *et al.* 2009; Arne *et al.* 2014). Composites reinforced with natural fiber are used in various applications including building siding, roof tiles, windows, automobiles, and aerospace (Mulinari *et al.* 2009; Sathish 2015). Natural fibers from annually renewable resources are commonly employed as reinforcement or fillers in thermosets and thermoplastic matrices alternatives to synthetic fibers such as carbon, glass, and aramids (Cerqueira *et al*. 2011; Pereira *et al*. 2011; Petchwattana *et al*. 2012). Their attractive features, including low cost, low density, versatility, renewability, good mechanical properties, non-abrasiveness and eco-friendly nature, and bio-degradability make natural fibers preferable to conventional synthetic fibers (Ku *et al*. 2011; Jayamani *et al*. 2015).

Several annual plant fibers such as rape grass straw, sisal, jute, coir, bagasse, wheat

straw, flax, and *Luffa cylindrica* fibers have been studied as reinforcements or fillers in polymer composites (Avella *et al.* 1995; Dogherty *et al.* 1995; Wambua *et al.* 2003; Frounchi *et al.* 2007; Bledzk *et al.* 2010; Maneesh *et al.* 2012; Zhang *et al.* 2016). These fiber reinforcements improve the mechanical strengths and thermal stability of the composites (Panthapulakkal *et al.* 2006; Alemdar and Sain 2008; Zou *et al.* 2008; Mominul *et al.* 2009; Ravindra *et al.* 2010; Arrakiz *et al.* 2013). Most studies have demonstrated that natural fiber reinforcement in polymer matrices substantially improves the desirable characteristics of composite materials in engineering applications, demonstrating the advantages of these fibers over synthetic glass and carbon fibers (Panthapulakkal *et al.* 2006; Jayamani *et al.* 2015).

However, the use of natural fiber reinforcement in the polymer matrices is usually hindered because of the lack of compatibility between the polar natural fibers and nonpolar polymer matrices (Wambua *et al.* 2003; Maneesh *et al.* 2012). Enhanced compatibility between natural fibers and polymer matrices has been achieved commonly by two methods: fiber surface treatment and chemical coupling agents (Toress and Cubillas 2005; Petchwattana *et al.* 2012). Mengeloglu *et al*. (2007) reported that the use of maleated polypropylene (MAPP) coupling agent can significantly increase the tensile strength and tensile modulus of both HDPE-WFC and PP-WFC composite. Moreover they showed that the MAPP coupling agent slightly increased the flexural strength of HDPE-WFC. Alkaline treatment of natural fiber surfaces is the most widely used method to modify fiber surfaces and improve the interfacial interaction and adhesion between the fiber and polymer matrix. Chen *et al.* (2016a) showed that alkaline treatment of natural fiber induces surface roughness and fibrillation that provide site of mechanical interlocking between fiber and matrix.

Lemongrass (*Cymbopogon* species), one of the most extensively grown perennial plants in tropical and subtropical parts of the world, is an aromatic plant mainly cultivated as a source of essential oils (Valtcho *et al.* 2011). The steam distillation extraction process of lemongrass for essential oil production releases a lignocellulosic biomass or residue. Globally, approximately 30,000,000 tons *per annum* of lignocellulosic lemongrass residue are generated from industrial extraction processes (Kaur *et al.* 2010). Lemongrass is composed of cellulose-rich fibers that can serve as a potential raw material source for various areas of application including pulp and paper (Omar *et al*. 2015). Lemongrass is a rich lignocellulosic material comprised of holocellulose (68.51%), α-cellulose (35.0 to 44.16%), and lignin (17.39 to 27.38%) (Kaur and Dutt 2013). In spite of its high fiber content lemongrass has not been characterized as reinforcement for thermoplastics.

The main aim of this research was to characterize lemongrass fibers and investigate its reinforcement properties in thermoplastics.

EXPERIMENTAL

Materials

Mature lemongrasses with an average size 68 cm were mowed from the lemongrass field in Nanjing Tech University, China. An analytical grade virgin high density polyethylene (HDPE, 5000s, melt flow index of 0.90 g/min, density of 0.954 g/cm^3, and melting point of 130 °C) was used as a matrix, and maleic anhydride grafted polypropylene (MA-g-PP) served as a coupling agent. Both were supplied by Sinopec Yangzi Petrochemical Co. Ltd., Nanjing, China. The LDPE with melt flow index of 2g/10min, density 0.916 g/cm^3 and melting point 122°C was also obtained from the same company.

It was used as matrix blend with HDPE to improve the flexibility in wicker product.

Fiber Preparation

Lemongrass collected from the field was air dried for 3 days and chopped into 2- to 5-cm long pieces. Half of the cut lemongrass fiber was modified by immersion in 0.5% $Ca(OH)_2$ solution for 6 h. At the end of immersion period, the fiber was thoroughly washed with tap water until the pH of the water was neutral. Both the modified and raw fibers were independently oven dried at 80 °C for 24 h to lower the moisture content below 3% prior to grinding. The moisture content was determined using a moisture analyzer (MA35M 000230V1, Sartorius Scientific Instruments Co. Ltd., Beijing, China). The dried materials were hammer milled with continuous feed mill (DLF18, Wenzhou Dingli Medical Instruments Co. Ltd., Wenzhou, China) and sieved with a Sieve Shaker Retsch-AS300 (Newtown, MA, USA) into varying particle size distributions. The powdered material was stored in sealed plastic bags to curtail moisture absorption. The lemongrass fibers were examined with an optical microscope (Olympus BX43, Tokyo, Japan).

Chemical Analysis of Lemongrass

The lignocellulosic components of lemongrass (modified and raw) fibers were determined by chemical analysis as described by Andrzej *et al.* (2010). Ash content was tested using TAPPI test method 211om-02 (2002).

Preparation of Composite

A varying volume fraction (10%, 20%, 30%, 40%, and 50%) of lemongrass flour with particle sizes ranging from µm 850 µm to 150 µm was homogeneously mixed with virgin HDPE and 3% MA-g-PP using a laboratory pan. The melt blending method was used to homogeneously compound the components using a counter rotating twine hot-press mixer for each sample at 175 °C for 7 to 10 min.

Two stainless steel sheets, one with an engraved squared casting area (200 mm × 200 mm × 4 mm) and another plane sheet were used as a molding plate for casting the composite. The homogeneously blended compound was mounted between the plates and compression casted into composite panels using the compression machine SLB-25-D350 Carver hydraulic hot-press (Suyan Science and Technology Corporation, Nanjing, China) at a temperature of 190 °C and pressure of 15 MPa. Two composite panels were prepared for each composite type. The casting sheet was inverted three times at 5-min intervals to assure complete unification and even distribution of the composite materials along the whole casting area. The molded composite panels were then cooled by placing the sheets in the cooler compartment of the compression machine at 15 MPa prior to separating it from the casting plate. The composite panel was then conditioned according to ASTM D618-05 (2005) prior to testing. Flexural properties test specimens sized 80 mm × 10 mm × 4 mm in length, width, and thickness, respectively were made from conditioned composite panels using a Profile Specimen Maker XXZ-II (Jinjian Testing Instruments Corporation, China). Five "dog bone" specimens were also prepared for tensile testing with a Dumbbell Specimen Maker XYZ-20 (Jinjian Testing Instruments Corporation).

Product Fabrication

After a lab scale thorough investigation of the reinforced composites for their physical and mechanical properties, lemongrass fiber was used to produce reinforced polymer matrix composite wicker. A total of 10% modified lemongrass flour was homogeneously mixed with 48% HDPE, and 39% LDPE. A low-density polyethylene matrix was added to these samples to improve the flexibility of the wicker product. The

mix was extruded through an extrusion machine (Nanjing Coperion Machinery Company, Nanjing, China) with heating zones set at 180 °C, 165 °C, 165 °C, 170 °C, 175 °C, and 180 °C and cooled under fanned wind prior to being cut into pellets. Pellets were mixed with 1% colorant and used to produce wicker in another extrusion machine (Dongguan Yao Ann Plastic Machinery Co. Ltd., Guangzhou, China) set at 180 °C, 170 °C, 170 °C, 175 °C, and 180 °C temperature zones. The extruded wicker was cooled by passing through running water. The fabricated wicker product was tested for its tensile properties.

Characterization

The fibers and composites prepared in this study were fully characterized using thermogravimetric analysis, scanning electron microscopy, Fourier transform infrared spectroscopy, and testing for mechanical properties.

Thermogravimetric analysis (TGA)

The thermal decomposition of the composites reinforced with 10% modified or raw lemongrass fiber and neat polymer was assessed by a thermogravimetric analyzer (Netzsch STA 449F3 TGA, Düsseldorf, Germany). The test was done in a nitrogen atmosphere under a flow rate of 60 mL/min to prevent oxidation. Approximately 20 mg of each sample was placed on a platinum pan and heated from ambient temperature to 600 °C at a heating rate of 10 °C/min to yield the maximum temperature decomposition peak. The mass loss due to thermal degradation was analyzed as a function of temperature.

Scanning electron microscopy

Scanning electron microscopy (SEM) of both modified and raw fibers and of composites reinforced with 10% raw lemongrass or 10% alkaline modified lemongrass fiber was used to evaluate the interfacial bonding strength between fiber particles and polymer matrix. In addition, the dispersion of fiber particles in the polymer matrix was analyzed. The selected composites were frozen in liquid nitrogen for 50 seconds, fractured, mounted on plate with black sticky band, and gold sputtered prior to microscopic analysis with a scanning electron microscope (TM3000, Hitachi, Tokyo, Japan).

FT-IR analysis

Fourier transform infrared spectra of raw and alkali modified lemongrass fine particles were recorded using the KBr (potassium bromide) technique. A PerkinElmer 100 Series FT-IR 1650 spectrometer (Waltham, MA, USA) was employed at a resolution of 440 to 4000 cm^{-1}. In each case, 1% (w/w) of oven dried lemongrass flour was dispersed homogeneously in KBr matrix and pressed into a thin circular sheet a few mm in radius.

Tensile and flexural tests

Testing of tensile properties was conducted according to ASTM D 638 (2012) using a UTM-1422 JJ-Test universal testing machine (Jinjian Testing Instrument Corporation). Five "dog-bone" specimens of 110 mm × 50 mm × 4 mm in grip distance, gauge length, and thickness, respectively, were tested at a crosshead speed of 1.9 mm/min. The flexural properties were tested according to ASTM D790 (2010), using the aforementioned testing machine applying a 3-point bending method at an average testing speed of 2 mm/min and 10 kN load cell. Five specimens of 80 mm × 10 mm × 4 mm in length, width, and thickness, respectively, were tested to determine the flexural properties of each composite type.

Izod impact resistance testing

The testing for impact strength was conducted using notched specimens according to the ASTM D256-05 (2005) standard with an impact measuring apparatus (Pendulum Impact Tester XJUD-5.5, Chengde, China). For each composite type, five notched specimens measuring 80 mm × 10 mm × 4 mm in length, width, and thickness, respectively, and with 2 mm depth notched at one side were tested. The impact energy was calculated in J/m^2.

The overall process for the characterization of lemongrass fiber as reinforcement in thermoplastic composites is presented in Fig. 1.

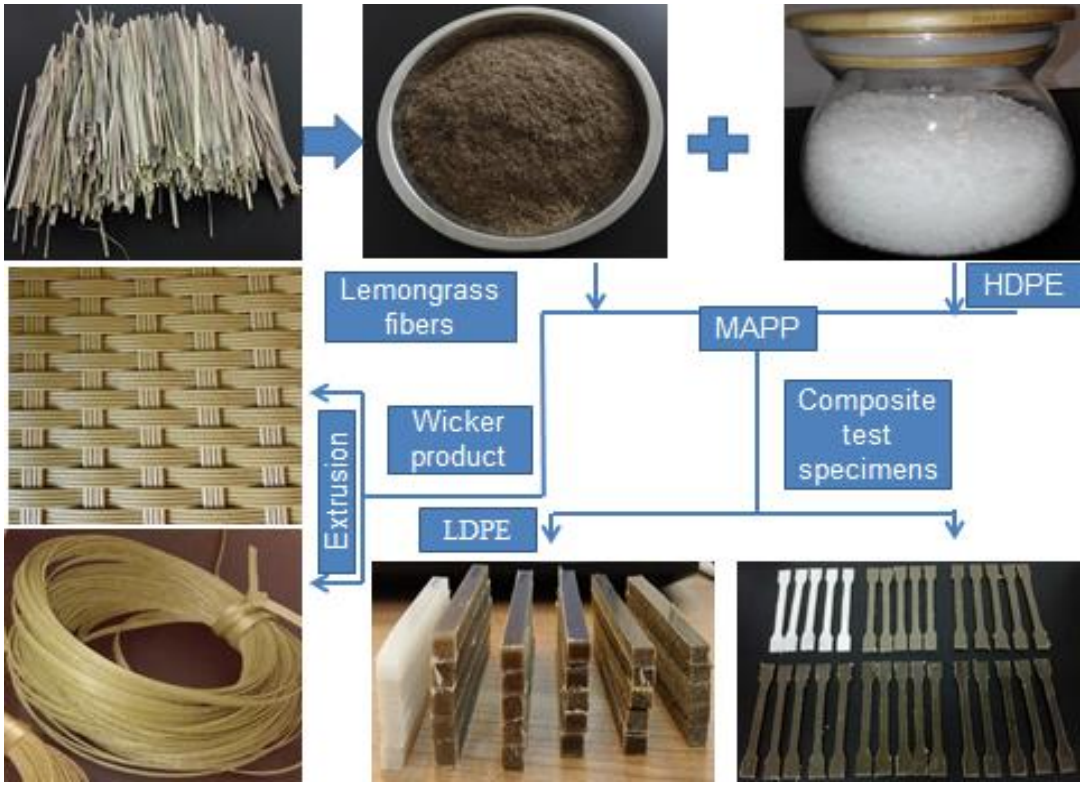

Fig. 1. Schematic presentation of the process line followed for fiber preparation and composite fabrication

RESULT AND DISCUSSION

Fiber Size Analysis

The ground lemongrass was fractionated into four size ranges of > 850 μm, 850 to 250 μm, 249 to 150 μm, and < 150 μm fiber particles. Figure 2 shows the lemongrass fiber particle size distribution.

Whole ground lemongrass fiber was microscopically examined to analyze the distribution of fiber particles based on their morphological appearance. The lemongrass particles consisted of cells of various cellular morphology including hexagonal, rectangular, elongated, and ovoid cells. The hexagonal cells and rectangular cells were dominant on the sheath of the lemon grass, while the elongated and ovoid cells were found predominantly distributed along the medial and lateral parts.

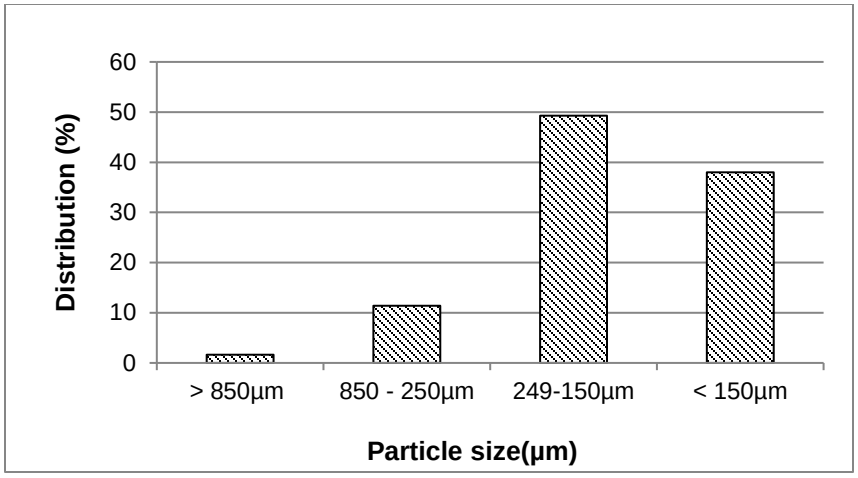

Fig. 2. Particle size distribution of lemongrass fiber

Figure 3 shows the micrographs of lemongrass cells. The hexagonal and rectangular cells were predominantly observed in finely ground fibers (< 150 µm), while the elongated and ovoid cells were found more often in fibers with higher particle size (850 to 250 µm). Fibers with particle sizes of 249 to 150 µm consisted of cells of all morphological appearance. The distribution of ovoid and elongated cells in fibers with large particle size shows that fibers with such cells resist the grinding force more than fiber dominated by other cell types. Fiber particles with sizes more than 850 µm were predominantly comprised of morphologically elongated cells. The analysis was employed as a base for recruiting the lemongrass fiber particles sizes for reinforcement in HDPE matrix composites.

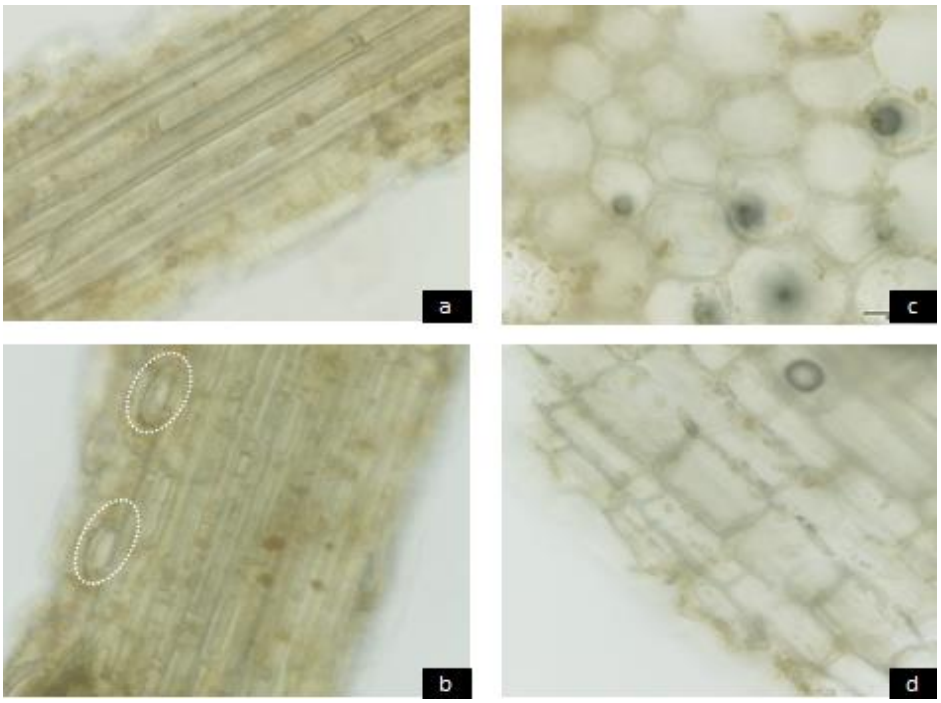

Fig. 3. Micrographs of lemongrass fiber cell morphology: (a) elongated (850 to 250 µm), (b) ovoid and elongated (850 to 250 µm), (c) hexagonal (< 150 µm), and (d) rectangular (< 150 µm)

Fibers with particle size ranging from 850 µm to 150 µm were used for composite synthesis. Fibers larger than 850 µm were avoided to prevent fiber agglomeration, which can arise from the entanglement of long fibers, leading to poor mechanical properties. It has been described that long fibers easily cluster in the matrix and affect the performances of the reinforced composite (Yao *et al*. 2008a).

Chemical Composition of Lemongrass

The chemical analysis of lemongrass fiber is presented in Table 1. Lemongrass fiber consisted of lignocellulosic materials comprising of a high amount of cellulose, hemicellulose, and lignin. Cellulose was the predominant component, followed by hemicellulose and lignin. The level of lignocellulosic components in modified fiber was predominantly cellulose (85%). Alkaline treatment removes hemicellulose, lignin, wax and oils covering the external surface of the fiber cell wall (Li *et al*. 2007). The remarkably high amount of cellulose makes the lemongrass a reliable candidate as a reinforcement material in polymer matrix composites.

Table 1. Pre and Post Treatment Chemical Contents of Lemongrass

Chemical Components	Raw Lemongrass (%)	Modified Lemongrass (%)
Cellulose	39.5	71.7
Hemicellulose	22.6	9.52
Lignin	28.5	13.83
Ash	1.5	0.65
Moisture	6.8	3.84

Thermogravimetric Analysis

Thermogravimetric analysis was conducted to determine the thermal stability of modified and raw lemongrass fibers and composites reinforced with the respective fiber types. The TGA and DTG reading curve of modified and raw lemongrass fibers and their respective composites are shown in Fig. 4 (a & b). Weight loss in the thermal degradation process of lemongrass occurred in four successive phases. The initial weight loss of the fibers in the thermal range of 38 to 110 °C occurred due to the removal of moisture and some volatile components in the fibers through evaporation (Rosa *et al.* 2010). The weight loss due to water evaporation was remarkably higher (7.4%) in raw fibers than in modified fibers, implying higher moisture content in raw fibers. This can be explained as a higher moisture absorption and more hydrophilic tendency of the raw fiber. The second weight loss (210 to 310 °C) was associated with degradation of amorphous hemicellulose components and glycosidic linkages in cellulose. Hemicellulose is the least thermally stable component (Ramiah 1970). The third phase of weight loss from 350 to 390 °C was associated with the thermal degradation of alpha cellulose (Bledzki *et al.* 2010). These findings are in agreement with TGA of other natural fibers (Alemdar and Sain 2008; Yao *et al*. 2008b). A higher onset of degradation temperature was recorded for alkaline modified lemongrass fiber. This result clearly shows that alkaline treatment improved the thermal stability of the lemongrass fiber by removing some easily degradable fiber components including hemicellulose, pectin, and wax that would otherwise degrade quickly. Early thermal degradation in raw lemongrass fibers is attributed to the presence of higher amount of hemicellulose in fiber (Elkhaoulani *et al.* 2013).

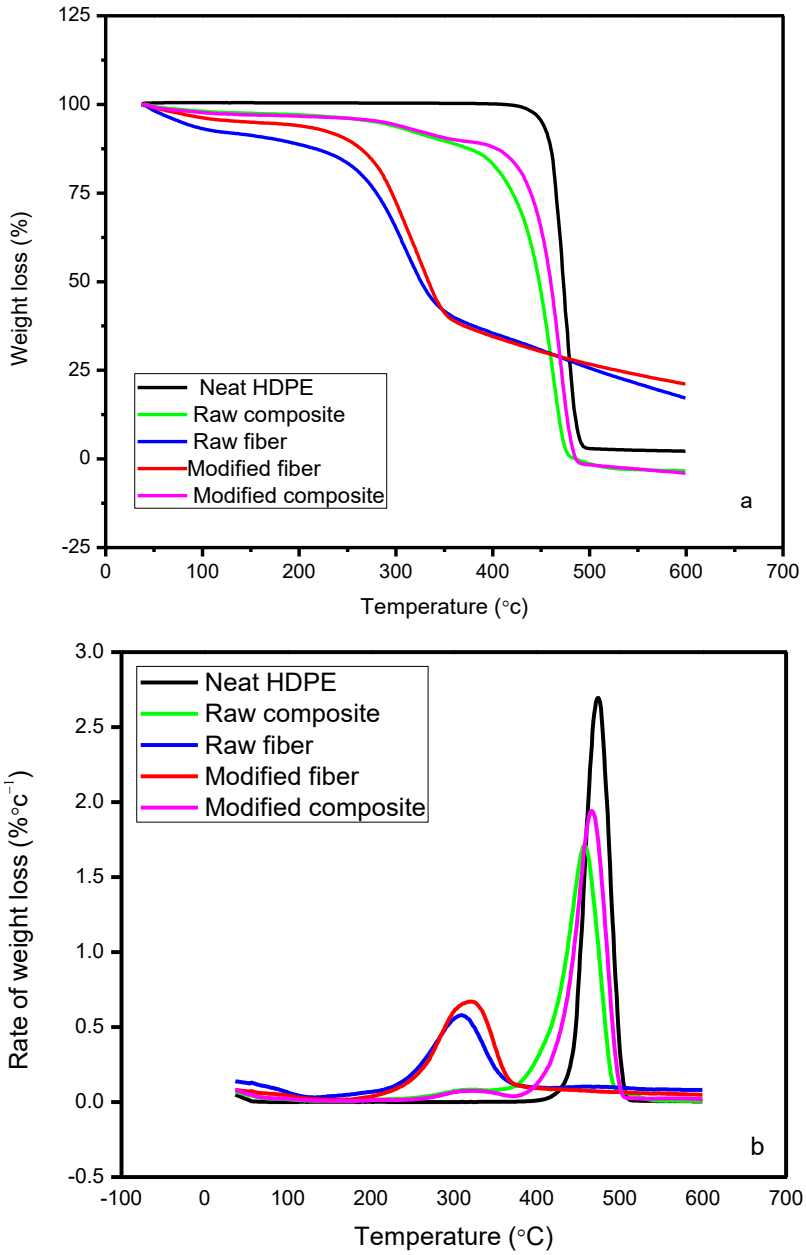

Fig. 4. TGA (a) and dTGA (b) thermographs of alkaline modified and raw lemongrass fiber, neat HDPE, and composites reinforced with 10% alkaline modified or raw lemongrass fiber

The onset of thermal degradation of composites reinforced with alkaline modified lemongrass fiber particles was higher than that of raw fiber reinforced biocomposite. The improvement in thermal stability in modified lemongrass fiber reinforced composite is linked with better thermal stability of the fiber following alkaline treatment. However, the overall thermal stability of the composite was somehow lower than the thermal degradation values of the neat HDPE matrix. The incorporation of lemongrass particles into polymer matrices improved the thermal degradation point of the polymer matrix composite. The terminal residue, at the end of the thermal degradation process of both fiber and composites pyrolysis represents ash devoid of all volatile components and remnant lignin (Yang *et al.* 2007).

Scanning Electron Microscopy

Scanning electron microscopy of alkaline modified and raw lemongrass fiber particles is shown is Fig. 5. The micrographs clearly showed the structural difference between alkaline modified and raw fiber particles. Clearly visible changes occurred on the surface appearance of the modified fiber. As shown in the Fig. 5(a & b) the modified fiber surface appeared rough, devoid of surface impurities, and it possessed many indented surfaces structures due to defibrillation and washing way of amorphous chemical components. Alemdar and Sain (2008) also reported that chemical treatment of wheat straw resulted in alteration of the surface structure and chemical composition of the fiber. The development of such changes on the surface structure of the fiber creates advantages for binding through mechanical interlocking between the fiber and polymer matrix in the composites (Chen *et al.* 2016a). Conversely, raw fiber surface structure appeared devoid of surface indentations and covered with numerous impurities, as indicated in Fig. 5 (c & d).

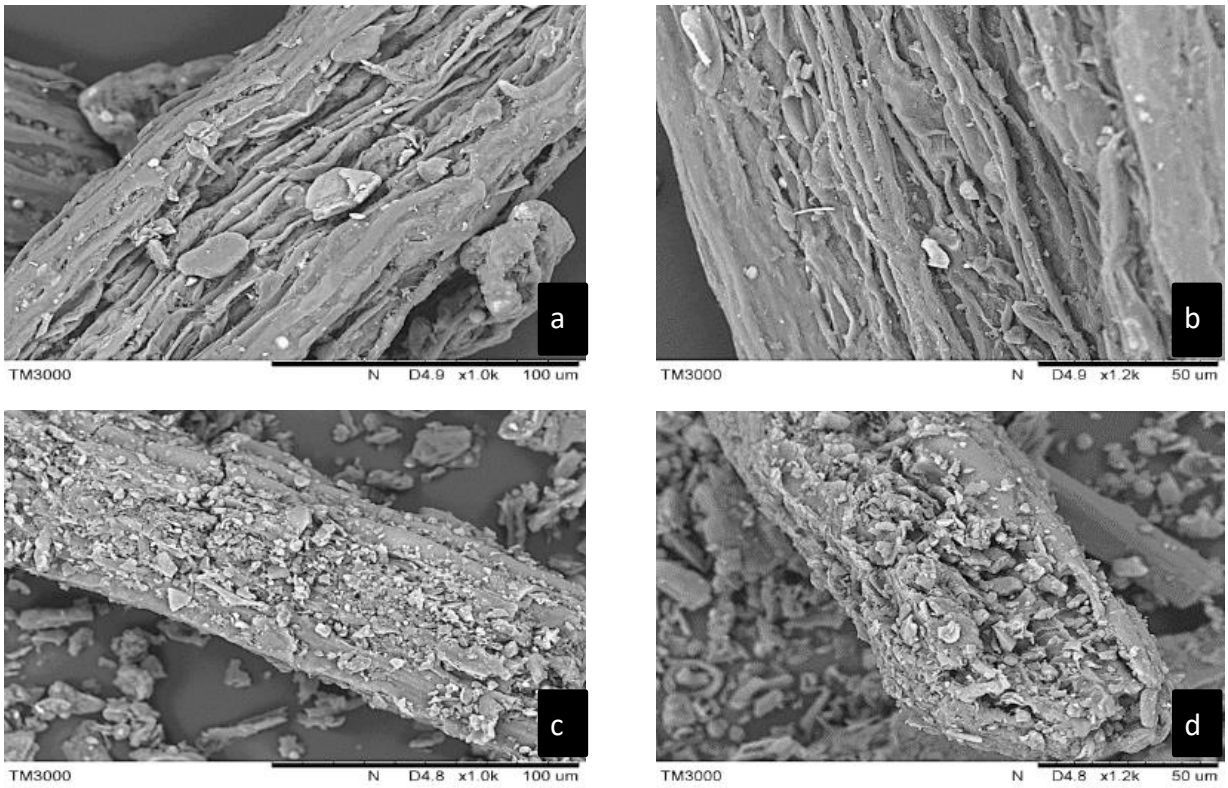

Fig. 5. Scanning electron microscopy of (a, b) alkaline modified and (c,d) raw lemongrass fiber

The SEM micrographs of the two composites filled with alkaline modified and raw lemongrass flour are illustrated in Fig. 6. Composites filled with alkaline modified lemongrass flour showed good fiber to matrix interactions and hence, were tightly embedded in the matrix Fig. 6 (a & b). Poor fiber to matrix binding was clearly observed among composites consisting of raw fiber; it was expressed as visible loss attachment between the fiber particles and the matrix and pullout Fig. 6(c & d). These results indicate that alkaline modification remarkably improved the interface between the hydrophilic fiber particles and hydrophobic HDPE matrix.

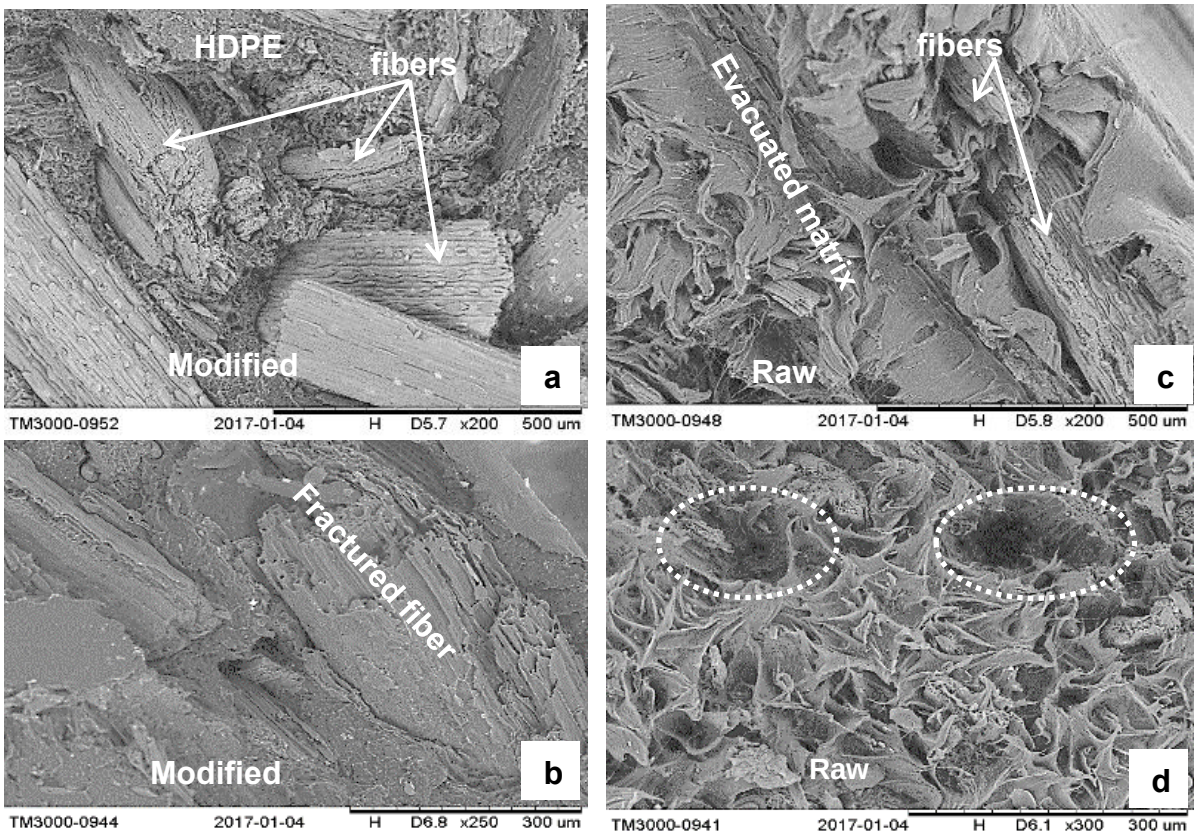

Fig. 6. SEM micrograph of HDPE/Lemongrass-fiber composite fracture surfaces: (a & b) polymer matrix composites reinforced with modified fiber; (c and d) reinforced with raw fiber

Spectroscopic Analysis

Fourier transform infrared spectroscopy was used to study the physicochemical changes that occurred following modification of lemongrass fiber surface. Figure 7 shows the FT-IR spectra of alkaline modified and raw lemongrass fiber.

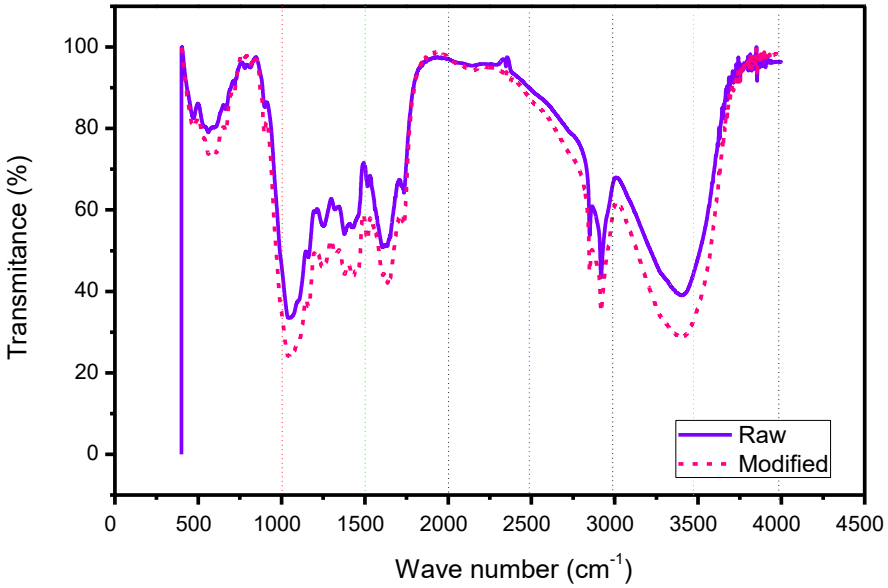

Fig. 7. FT-IR spectra of alkaline modified and raw lemongrass fiber

The bands at 1737 cm^{-1}, 1620 cm-1, and 1515 cm^{-1} in unmodified fiber were attributed to the aliphatic, aromatic, and ester functional groups, respectively, which are present in the hemicellulose, wax, and pectin. The dominant spectrum at 3420 cm^{-1} corresponds to the O-H stretch the aliphatic stretch in moieties of cellulose (Sun *et al.* 2005). The prominent peak at 2921 cm^{-1} of modified lemongrass fiber is due to the C-H stretching from saturated aliphatic compounds. This stretching peak corresponds to the aliphatic moiety in cellulose (Cherian *et al.* 2008). The band at about 1739 cm^{-1} is due to the C=O stretching of the acetyl group and linked to the ester linkage of carboxylic group of the ferulic acid and p-coumaric acid of lignin (Sun *et al.* 2005). The band at 1371 cm^{-1} is due to C-H symmetric and asymmetric stretch. The prominent peak at 1029 cm^{-1} in modified fiber represents the C-O stretching and deformation band in cellulose and lignin (Bledzki *et al.* 2008).

Table 2. FT-IR Spectral Bands of Modified and Raw Lemongrass Fiber

Frequency (cm^{-1})	Vibration	Functional groups/assignments
1029	C-O stretch	Alkyl
1187	N-H stretch	Organic sulphate
1371	C-H asymmetric bend	Aliphatic nitro compounds
1515	N-O symmetric stretch	Aromatic nitro compounds
1620	N-H bend	Carboxylic acid salt
1739	C=O unconjugated stretching	Aldehyde
2921	C-H stretching	Aliphatic saturated compounds
3000	C-H stretch	Alkanes
3420	O-H stretch	Hydroxyl

Tensile Properties

The tensile strength (TS) values of alkaline-modified and raw lemongrass reinforced HDPE composites at different fiber volume fractions are shown in Fig. 8. An increase in filler loading led to substantial increases in the TS of the composites reinforced with 10% modified fiber. There was a 13.2% (22.0 MPa) increase in the TS values among composite panels reinforced with 10% modified fibers compared with the 19.4 MPa values in neat HDPE.

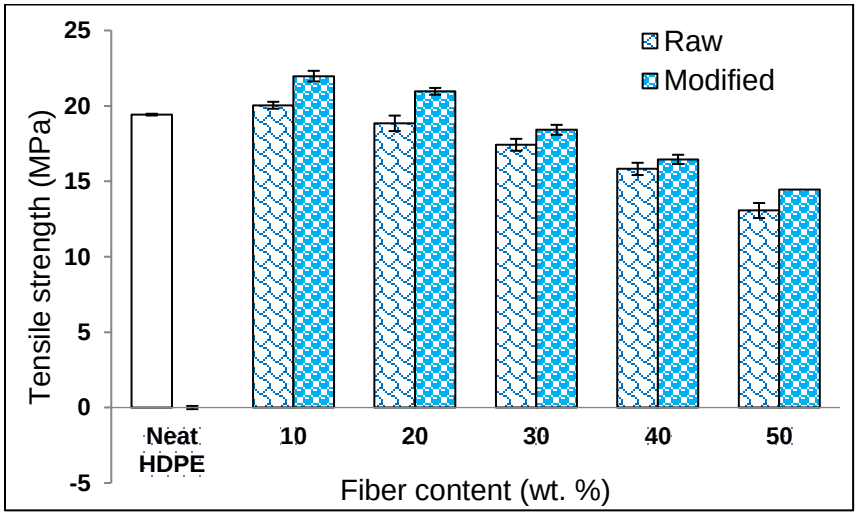

Fig. 8. Tensile strength versus fiber content of lemongrass/HDPE composites

There was also a 3.2% (20.0 MPa) increase in TS value of composite reinforced with 10% raw lemongrass fiber. The TS value tended to decrease as the fiber content increased beyond the 10% optimum level. The increase in fiber volume fraction induces weak fiber to matrix interfacial interactions and leads to poor tensile strength of the resulting composites (Mominul *et al.* 2009).

The interfacial bonding between the lemongrass fiber and HDPE matrix was increased by the alkaline treatment of fiber surface. The alkaline treatment obviously increased the tensile strength. The fiber surface alkaline treatment removed hemicellulose, lignin, wax, fat, and pectin, inducing surface roughness and hydrophobicity of the fiber surface. All changes on the fiber surface improve the interfacial adhesion through mechanical and chemical bonding methods (Pickering *et al.* 2016).

Flexural Modulus

The flexural modulus of raw and alkali modified lemongrass fiber flour filled HDPE composites versus fiber volume fraction are shown in Fig.9. The flexural moduli of composites substantially increased as the fiber content was increased. The maximum peak flexural strength value (2398 MPa) was recorded for composites filled with 30 wt.% volume fraction. The increasing trend in flexural modulus as flour content of lemongrass fiber increased was anticipated because of the subsequent increase in stiffness of the reinforced polymer matrix. The present finding is in close agreement with other reports in the literature (Shibata *et al*. 2006; Reddy *et al*. 2010).

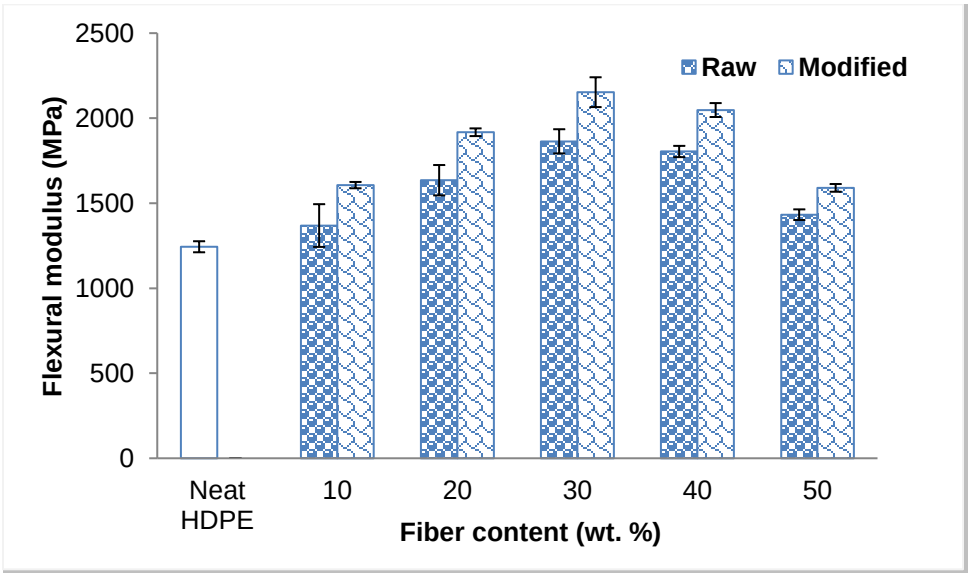

Fig. 9. Flexural modulus versus fiber content of lemongrass/HDPE composites

Izod Impact Strength

The notched Izod impact strength test results versus fiber content are shown in Fig. 10. These results show that the Izod impact strength progressively decreased as the fiber content increased. The decrease in impact strength at high fiber contents can be associated with increased brittle characteristics of the fiber and gradual loss of ductile property in the composites. In other work, it is reported that poor interfacial bonding causes micro-space between the filler and matrix interfaces leading to the development of micro-cracks that in turn enhances fracture propagation (Yang *et al.* 2004). It was also stated that at high filler concentration, there are lots of fiber interactions as a result of the agglomeration of fibers

in the composites where it is more sensitive to crack than the matrix-fiber interface (Salasinska and Ryszkowska 2015; Chen *et al.* 2016b). Mengeloglu and Karakus (2012) also reported that increasing fiber loading decreases the impact strength value. The impact strength value was higher among composites reinforced with alkaline modified fiber as compared to composites reinforced by equivalent amounts of raw fiber. Strong interfacial interaction and firm adhesion between modified fibers and the matrix interfaces resulted in relatively high impact strength among modified fiber filled composites as compared with those filled with raw fibers. Alkaline treatment is reported to remove the lignin and hemicellulose, leading to better packing of cellulose chains and maximum fiber crystallinity that contributes to the toughness of the composite and hence improved impact strength of the composite (Bachtiar *et al.* 2009). Nevertheless, in this case also the impact strength tended to decrease with the increase in filler loading.

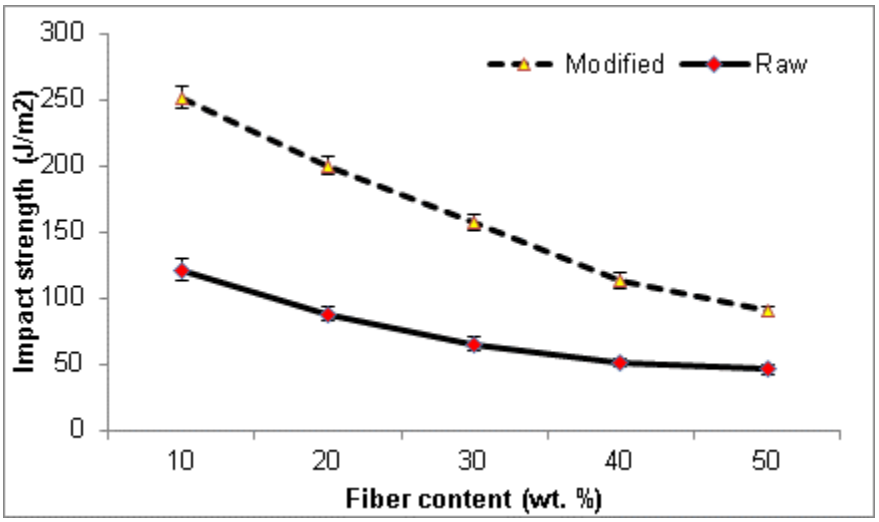

Fig. 10. Impact strength versus fiber content of lemongrass/HDPE composites

The lemongrass fiber investigated under lab conditions was utilized to reinforce polymer matrix composite wicker, the type most commonly utilized material for furniture making. The wicker produced under the current pilot study showed better tensile strength of 8.99 MPa compared to the value in neat matrix wicker (Fig. 11).

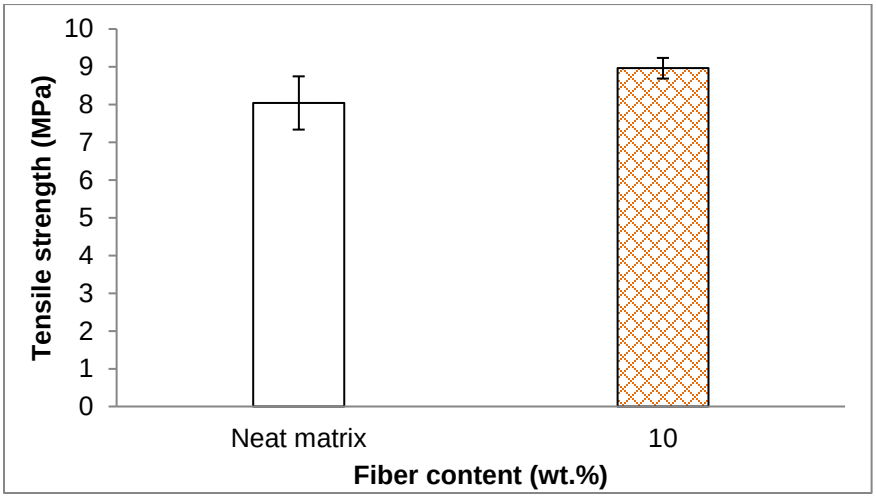

Fig. 11. Tensile strength of wicker made neat thermoplastics and 10 wt.% lemongrass fiber

The tensile strength value recorded for the composite wicker reinforced with 10% modified lemongrass was by 11.8% higher compared to the 8.04 MPa tensile strength value recorded in neat polymer wicker.

CONCLUSIONS

1. Chemical analyses showed that lemongrass fiber contains lignocellulosic components in amount higher or equivalent to most of the natural fibers commonly utilized to reinforce thermoplastics and thermosets matrix composites. Cellulose was the major lignocellulosic component, and its proportion was markedly increased following alkaline modification.
2. The TGA analysis of the fiber revealed that lemongrass fiber has a relatively high thermal degradation temperature. Moreover, alkaline modification highly improved the degradation temperature of the fiber.
3. The SEM micrograph and FT-IR analysis clearly demonstrated that the surface structure and surface functionality of the lemongrass fiber, respectively changed remarkably following alkaline modification.
4. The use of lemongrass fiber reinforcement in thermoplastics substantially improved the mechanical performance and thermal properties of the composites. Higher improvement in the mechanical performances and thermal properties were measured among composites reinforced with alkaline modified fiber.

ACKNOWLEDGMENTS

This work was supported by the Ministry of Science and Technology of the People's Republic of China - National Key Technology Support Program (No. 2012BAC17B00) and the bidding project of Zunyi Medical University (No. F-803).

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Article submitted: April 13, 2017; Peer review completed: June 10, 2017; Revised version received: June 15, 2017; Accepted: June 16, 2017; Published: June 26, 2017.
DOI: 10.15376/biores.12.3.5664-5681