

An investigation of sound absorption coefficient on sisal fiber poly lactic acid bio-composites

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ABSTRACT: In this research, the mechanical, acoustical, thermal, morphological, and infrared spectral properties of untreated, heat and alkaline-treated sisal fiber-reinforced poly-lactic-acid bio-composites were analyzed. The bio-composite samples were fabricated using a hot press molding machine. The properties mentioned above were evaluated and compared with heat-treated and alkaline-treated sisal fibers. Composites with heat-treated sisal fibers were found to exhibit the best mechanical properties. Thermogravimetric analysis (TGA) was conducted to study the thermal degradation of the bio-composite samples. It was discovered that the PLA-sisal composites with optimal heat-treated at 160°C and alkaline-treated fibers possess good thermal stability as compared with untreated fiber. The results indicated that the composites prepared with 30wt % of sisal had the highest sound absorption as compared with other composites. Evidence of the successful reaction of sodium hydroxide and heat treatment of the sisal fibers was provided by the infrared spectrum and implied by decreased bands at certain wavenumbers. Observations based on scanning electron microscopy of the fracture surface of the composites showed the effect of alkaline and heat treatment on the fiber surface and improved fiber-matrix adhesion. © 2015 Wiley Periodicals, Inc. *J. Appl. Polym. Sci.* **2015**, *132*, 42470.

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INTRODUCTION

In the past few decades, natural fibers extracted from plants, animals, and minerals have been receiving more attention than non-natural exploited petroleum-based fibers. This is because natural fibers are more ecologically friendly and produce a smaller carbon foot print.¹ Conventionally, fiber reinforced composites are fabricated using synthetic fibers and thermoplastic or thermoset resins. The synthetic fibers (aramids and graphite), thermoplastic resins (polyolefin and nylons), and thermoset resins (epoxies) are derived from petroleum.² However, the use of petroleum in synthetic fibers, thermoplastic resins, and thermoset resins causes negative environmental impacts because of their non-biodegradable properties. Similarly, the price of these petroleum-based synthetic fibers and plastic resins has increased because of the unpredictable prevailing in the supply of petroleum. With increasing environmental awareness and dwindling petroleum reserves, researchers have been encouraged to develop biodegradable and eco-friendly composite materials.³

Recently, the use of natural fibers such as coir, kenaf, bamboo, jute, sisal, banana, luffa, betel nut, ramie, and hemp as replace-

ments for synthetic fibers have received great attention in the industry. Typically, natural fibers properties are normally lightweight, nonhazardous, nonabrasive, renewable, biodegradable, and inexpensive. It also offers satisfactory performance of the mechanical properties when they are reinforced with polymer.⁴ However, the produced composites can only be down cycled and partially degraded because they are fabricated with petroleum-based polymer resins. These composites have a disposal problem at the end of their lives.⁵

Nowadays, the interest in natural fiber reinforced bio-polymer composites (green composites) is growing extensively in both research field and industry. Some examples of commonly used bio-polymers are poly-hydroxy-butyrate (PHB), poly-lactic-acid (PLA), and hyaluronate.⁶ Green composite seems to have significant potential because of its fully biodegradable features that are sustainable, and environmentally friendly. Therefore, it makes petroleum-based composites obsolete. However, green composites have some limitations in terms of their mechanical properties and possess only average physical properties. Thus, selection of the most appropriate natural fiber and bio-polymer

Table I. Chemical Composition of Sisal Fibers

Fiber	Latin name	Cellulose (wt %)	Hemicellulose (wt %)	Lignin (wt %)	Moisture content (wt %)	Waxes (wt %)	Pectin (wt %)
Sisal	<i>Agave sisalana perrine</i>	43–88	10–13	4–12	10–22	2	0.8–2.0

is important for obtaining the desired properties. In addition, many studies have been conducted on the modification of natural fibers and bio-polymer resins for enhancing mechanical and physical properties.⁵

Natural fiber reinforced composites have huge advantages over synthetic fibers in the automotive, aerospace, sports, electrical, and electronic industry applications. The most significant advantages are in terms of cost and weight. Averagely, natural fiber composites would cost 25–50% less than glass fiber composites. For example, in terms of physical properties, the densities of natural fibers seem to be less than the half of the density of glass fibers. This reduces energy consumption when natural fibers are used in the manufacturing of automobile parts instead of synthetic fibers. For instance, the weight of an injection molded acrylonitrile butadiene styrene (ABS) car door panel is 9 kg, while a similar panel manufactured with natural fibers weighs only 5 kg, and has mechanical properties almost equivalent to that of the ABS material.⁷

Natural fiber reinforced polymer composites are widely used in our daily life in a wide range of applications because of their low weight properties and the high exploited ability to be hand made for a specific end use.⁸ The resulting products can be both reused and incinerated. Unlike glass fiber composites, natural fiber composites do not need to be dumped into landfills because of its biodegradable properties. In addition, natural fibers exert some other beneficial properties, such as impact resistance, sound absorption, thermal insulation, as well as manufacturing processes. For impact resistance, natural fibers have a safer crash behavior in accident tests based on the absence of splintering.

The hollow cellular structure of natural fiber contributes to its good acoustic property. In terms of the manufacturing process, natural fibers are easier to cut and non-abrasive to processing equipment. On the other hand, glass fibers tend to blunt the tools used during manufacturing. Therefore, using natural fibers instead of synthetic fibers may contribute to the prolonged life of the equipment. In this research, untreated, heat and chemically treated sisal fibers were reinforced with poly-lactic-acid (PLA) to produce fully bio-degradable composites. The

performances of the bio-composites were characterized in terms of their mechanical, acoustical, thermal stability, and morphological properties, as well as by infrared spectra using various characterization techniques.

EXPERIMENTAL

Materials

Agave sisalana is a species that belongs to the agave family. It is a rosette-forming succulent plant mainly cultivated for its fibers which are extracted from the leaves.⁹ Sisal fibers were obtained from local sources. The chemical and mechanical properties of the sisal fibers are presented in Tables I and II, respectively.

Poly-lactide, or poly-lactic-acid, is one of the most popular biopolymers. Poly-lactic-acid is polyester made from lactic acid that is derived from natural resources such as corn.¹¹ The poly-lactic-acid (PLA), usually found in crystal form, is brittle and biologically degradable. It is produced from lactic acid (2-hydroxy-propane acid), when heated, forms a cyclic compound called di-lactide because of the splitting of water molecules in a condensation polymerization reaction.¹² A poly-lactic-acid with a density of 1.40 g/cm³, the melting point of 150°C, the melt index of 10–12 g/10 min, and the elongation break at 2% was supplied by Dalian Lejia Chemical (China) and used as the matrix material in this research.

Methods

Surface Modification of Fiber. Sisal fibers were subjected to surface treatments in order to improve the interfacial adhesion between the sisal fiber and the PLA matrix. Interfaces between the natural fiber and polymer matrix play an important role in the acoustical, spectral and mechanical properties of composite materials.

Chemical Treatment. Fibers were washed with a detergent solution at room temperature and then rinsed with water to remove dust and impurities. The alkaline solution was prepared by dissolving a measured quantity of sodium hydroxide (NaOH) pellets in the distilled water. The sisal fibers were immersed in 5 wt % aqueous NaOH solution for 2 h at room temperature. After NaOH treatment, the fibers were washed with distilled

Table II. Mechanical Properties of Sisal Fibers¹⁰

Fiber	Latin name	Density (g/cm ³)	Tensile strength (MPa)	Young modulus (GPa)	Elongation at break (%)
Sisal	<i>Agave sisalana perrine</i>	1.33	600–700	38	2–3

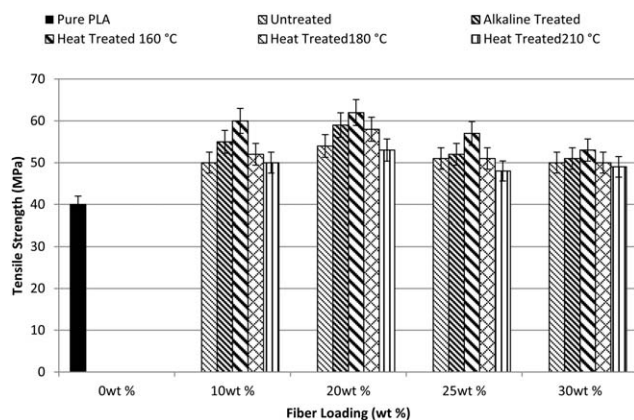


Figure 1. Tensile strength of the composites versus the fiber mass proportion.

water containing a few drops of acetic acid to neutralize them. Finally, the fibers were washed with distilled water to remove traces of NaOH and to bring the pH value to 7. The sisal fibers were then kept in a hot air oven with natural air convection for 5 h at 80°C. Alkaline treatment of fibers was expected to increase the surface roughness of the fibers. This aided in improving mechanical bonding between the fiber and the PLA matrix. The treatment also removed a significant amount of wax, pectin, hemicellulose, and lignin, thereby exposing more cellulose, which resulted in increased reaction sites for bonding with PLA.¹³

Physical Treatment. Heat treatment is a physical method that does not change the chemical composition of the fibers. Heat treatments of natural fibers are based on the fact that hemicellulose has a lower decomposition temperature than cellulose. Strong hydrophilic materials such as hemicelluloses can therefore be removed from the fibers by heating. This changes the molecular surface free energy and the structure of the fibers, and improves the interfacial adhesion between the hydrophilic fibers and the hydrophobic polymers.¹⁴ The fibers were chopped to an average length of 8 mm. The fibers were then heat-treated in an Ecocell EC55 oven (MMM Medcenter Einrichtungen GmbH (Germany), with natural air convection at temperatures of 160, 180, or 210°C for 10 min, respectively.

Fabrication of the Composites. Various molds fabricated according to the American Society for Testing and Materials (ASTM) standards were used to fabricate specimens for the tensile, flexural, impact, and sound absorption tests. The mold was lubricated with carnauba wax to prevent the PLA from sticking. The PLA and fiber mixtures were prepared with fiber contents of 10 wt %, 20 wt %, 25 wt %, or 30 wt % for both heat- and alkaline-treated fibers. PLA pellets were first crushed using a compression machine. They were then blended in a blending machine to convert the crushed pellets into refined powder form. Meanwhile, the sisal fibers were chopped to an average length of 8 mm. The PLA powder and chopped fibers were then mixed together in a mixing machine. The machine mixed the PLA and fiber at a low and constant speed. This ensured a thorough and even distribution of fiber among the PLA powder. This mixture was then arranged aptly inside the mold and then

compressed between the hot press plates at 145°C and 7 MPa. The mixture was heated for about 30 min (10 min for preheat the machine, 20 min for heating the PLA composites). After heating, the mold was left inside the 30 Ton Hydraulic Hot Press (LS-22071, Lotus Scientific Sdn. Bhd.; Malaysia) in a compression condition for 24 h to cool before removal. For sound absorption test, the circular mold diameter is 80 mm and the thickness is 5 mm.

Characterization of the Composites. The tensile, flexural, and impact strengths were determined using the following standards and instruments: ASTM D638-10¹⁵ standards using Universal Testing Machine-Tensile Machine (UTM107, T-machine; China); ASTM D790-10¹⁶ standards using a Universal Testing Machine-Three-Point Bending Machine (UTM107); and ASTM D6110-10¹⁹ standards using an LS-22-006-50J Charpy-Impact Testing Machine (Lotus Scientific Sdn. Bhd; Malaysia). A thermogravimetric analyzer (TA-60WS, Shimadzu Analysis Workstation (Japan)) was used to conduct thermal stability on the bio-composites. The bio-composites with a mass of 20 mg were heated from 30 to 900°C at a scanning rate of 10°C/min in a nitrogen atmosphere. A two-microphone transfer function impedance tube device, according to ASTM E1050-12¹⁸ standards, was used to measure the acoustical parameters in the range of 300–2000 Hz. The morphological studies of the heat and chemically treated composites were observed using a TM3030, Hitachi Tabletop Scanning Electron Microscope (Tokyo, Japan) with a field emission gun and an accelerating voltage of 15 kV. A FTIR-8101 Shimadzu Spectrometer (Japan) was used to collect the Fourier transform infrared spectrum and understand the functional groups of the heat and chemically treated fiber composites.

RESULTS AND DISCUSSION

Mechanical Properties

The mechanical properties of the composites were strongly determined by the fiber and matrix interface. The tensile strength of pure PLA, untreated, heat, and chemically treated sisal fiber PLA composites with different fiber loadings are presented in Figure 1. From Figure 1, it is clear that in both cases, tensile strength increases with fiber loading, and then starts to decrease after 25 wt % of fiber loading. However, it can be seen that the heat-treated fibers at 160°C showed the highest tensile strength. The tensile strengths of composites in descending order were as follows (strongest to weakest): heat treatment at 160°C, sodium hydroxide treatment, heat treatment at 180°C, untreated, heat treatment at 210°C and pure PLA. This was because of the fact that the heat treatment at 160°C improved the fiber surface adhesive characteristics by removing the artificial and other natural impurities. Therefore, it indirectly produces a rougher surface. It is interesting to take note that both thermal and chemical treatments enhanced the tensile properties of the composites hugely, but to varying degrees. Li *et al.*¹⁹ reported that the surface treated sisal fiber reinforced composites offered superior mechanical properties as compared with untreated fiber reinforced poly-lactide composites. This indicated that a better adhesion between fiber and matrix. Jayaraman²⁰ also reported that tensile strength showed an initial

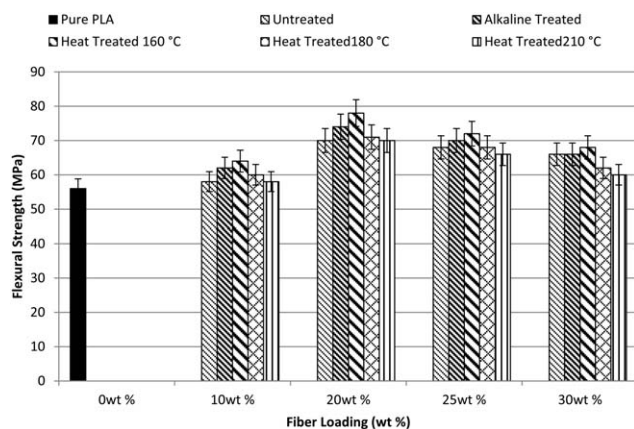


Figure 2. Flexural strength of the composites versus the fiber mass proportion.

decrease followed by a modest increase with increasing fiber content.

The flexural strength of the pure PLA, untreated, heat and chemically treated sisal fiber PLA composites plotted as a function of the fiber loading are shown in Figure 2. The fiber surface treatments had an effect on the flexural strength, similar to the observations made for the tensile strength. The best results were observed when the reinforcement surface had been treated with 160°C with a fiber loading of 20 wt %. However, the flexural strength of the composites with heat and chemically treated fibers decreased, which was inconsistent with the idea of good interfacial adhesion, which should improve the flexural strength of the composites. It was likely that the thermal and chemical treatments had a lasting effect on the natural fibers, such as the removal of amorphous components of the fibers, especially on fiber stiffness.^{21,22} The mechanical properties of the composites depend on the adhesion between fiber and matrix, in addition to the strength and modulus of the fiber and matrix. Even though the surface treatments adversely affected the strength and modulus of the fiber,^{22,23} the enhancement of the mechanical properties of the treated composites may be caused by better adhesion of the fiber and matrix.

Toughness is the main factor that controls impact strength. The impact resistance of a composite is the measure of the total energy dissipated in the material before final failure occurs. The impact strength results of pure PLA, untreated, heat and chemically treated sisal fiber PLA composites are shown in Figure 3. It shows that the impact strength of the composites increases with increasing fiber mass proportions. This is because of the introduction of fibers in the composites that increases the impact absorbance of the composite materials. It is known that the toughness of fiber reinforced polymer composites is depending on the fiber, the polymer matrix, and their interfacial bonding strength. From Figure 3, it can be seen that the impact strength of the composites was about 4 kJ/m². This was improved to about 8.7 kJ/m² with the incorporation of sisal fibers. The debonding, pull out, and fiber fractures are the mechanisms of energy absorption during impact.²⁴ Heat treatment of fibers at 180°C showed the best impact strength. Higher heat treatment temperatures do not show any positive effect on

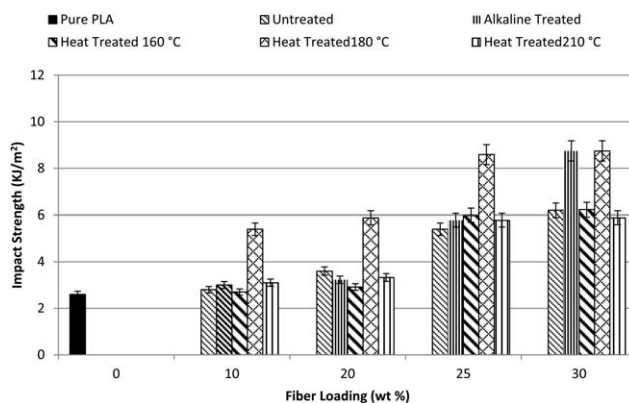


Figure 3. Impact strength of the composites versus the fiber mass proportion.

the impact strength of the composites. Bax and Müssig²⁵ also determined that the impact strength of the flax fiber PLA composites increased with increasing fiber loading. It appears that heat treatment at 180°C provides effective resistance to crack propagation during an impact test because of the improvement of interfacial adhesion.

Thermal Stability of Composites

The thermal degradation of heat and chemically treated sisal fiber PLA composites and pure poly-lactic-acid were investigated in terms of weight loss by thermo-gravimetric analysis (TGA) carried out in nitrogen, as shown in Figure 4. Evaluations of the thermal stability of the bio-composites are important in the determination of the limit of their service temperature under environmental conditions.²⁶

The degradation of pure polymer matrix PLA was a one-step process. The degradation process did not start until 370°C, but after 370°C it proceeded rapidly, and the polymer was completely degraded at 510°C. The onset of thermal decomposition of the bio-composites was slightly lower than that of the pure PLA, indicating that the introduction of natural fibers reduced thermal stability.²⁷ There were two degradation regions for the bio-composites (Figure 4). The first region was caused by the thermal degradation of cellulose, hemicellulose, and lignin in sisal fiber. The second region of higher temperature is associated

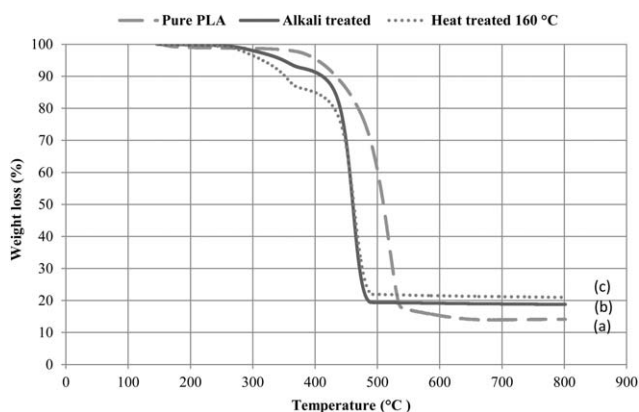


Figure 4. TGA thermo-grams of sisal PLA composites: (a) pure PLA; (b) sodium hydroxide-treated fibers and (c) heat treated at 160°C.

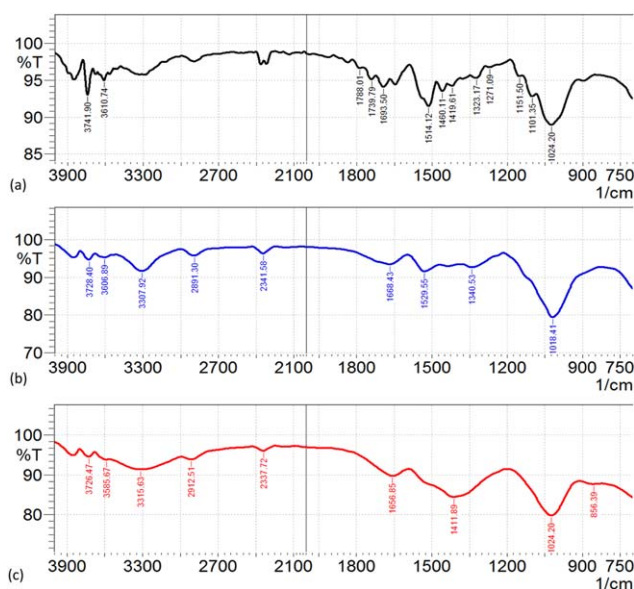


Figure 5. FTIR result for (a) untreated sisal fiber; (b) alkaline treated sisal fiber, and (c) heat treat sisal fibers at 160°C. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

with the depolymerization of poly-lactic-acid. Oza *et al.*²⁸ also found that the thermal degradation of hemp PLA composites showed a two-step degradation process. It can be observed that alkaline-treated sisal fiber PLA composites show higher thermal stability than heat treated sisal fiber PLA composites. In the case of alkaline treated fiber PLA composites, the thermal stability was higher because of the removal of organic impurities, such as pectin and waxes present on the surface of the sisal fibers, which exposed higher amounts of cellulose molecules.

For both alkaline- and heat-treated fibers, there was an initial mass loss observed below 100°C. This was because of the gradual evaporation of absorbed moisture in the fibers. The second mass start (from ~160 to 490°C) was caused by the decomposition of the three major lignocellulose components in the natural fibers. Hemicellulose decomposes between 150 and 350°C, cellulose between 275 and 350°C, and lignin between 250 and 490°C. Concerning the effect of treatment type on thermal behavior, it is worth mentioning that, in the first decomposition step, the heat-treated fibers showed the highest mass loss compared with the alkaline treated fibers. This was caused by the evaporation of some of the moisture during the heat treatment of fibers. Heat treatment temperatures of 160, 180, and 210°C influence the percentage of moisture loss in the fibers. With increasing heat treatment temperatures, the color of the sisal fibers gradually became brown, as observable by the naked eye; moreover, the fibers became rather brittle and broke easily.

Fourier Transform Infrared Spectral Analysis

A plot of measured infrared radiation intensity versus wavenumber is known as an infrared spectrum or infrared spectral. Heat and alkaline treatment of fibers led to differences in the infrared spectra, as shown in Figure 5(a–c) respectively. The FTIR spectra of the samples were recorded in the mid-range of wavenumber 4000 to 400 cm⁻¹. The results revealed that

alkaline treatment remarkably decreased the hemicellulose and pectin components from the fiber surface, whereas heat treatment showed an effect on the chemical components of sisal fibers. The peak at 1739.79 cm⁻¹ seen in untreated sisal fiber disappeared upon heat treatment at 160°C and alkaline treatment of the fibers. This was because of the conjugated C=O stretching vibration of Ph-(C=O) groups corresponding to lignin and absorbed water molecules in noncrystalline cellulose.²⁹ In addition, the peaks at 1460.11 cm⁻¹ (C–H deformation and CH₂ symmetric), 1271.09 cm⁻¹ (C–O bond of the acetyl group in xylan and hemicellulose), 1151.50 cm⁻¹ (anti-symmetric bridge C–OR–C stretching), 1101.35 cm⁻¹ (stretching C–OR), and 1024.20 cm⁻¹ (C–O and C–C stretching vibration in sisal) disappeared with alkaline treatment.³⁰ In the case of heat treatment of sisal fibers, the peaks at 1788.01 cm⁻¹ (C=O stretching vibration of carboxyl and acetyl groups in sisal), 1514.12 cm⁻¹ (C=C stretching vibration of aromatic ring in lignin), 1460.11 cm⁻¹ (C–H deformation vibration in lignin and carbohydrates), and 1693.50 cm⁻¹ (C–O–C stretching vibration in carbohydrates) disappeared.

Morphology Analysis

Scanning electron microscopy (SEM) is an excellent technique for examining the surface morphology of natural fibers and the fracture surfaces of natural fiber-reinforced polymer matrix composites. The SEM micrographs of the fractured surface of the heat and chemically treated and untreated sisal fiber composites can be seen in Figure 6(a–d). Figure 6(a) shows that the surfaces of the untreated fiber were completely devoid of matrix material. This was a clear indication of fiber-matrix interfacial failure followed by an extension fiber pullout from the matrix. The raw surface of the fiber consisted of a waxy substance called cuticle, which was from aliphatic origin and nonpolar in nature, which rendered it incompatible with the PLA matrix.³¹ From Figure 6(b–d) respectively, it can be inferred that fibers were tightly connected with the PLA matrix, which indicated better interfacial bonding between the fiber and matrix, which was improved by the alkaline and heat treatment of fibers. This tightly connected fiber and matrix led to an increase in the mechanical properties of the composites.

Sisal fiber-reinforced composite heat-treated at 160°C showed greater mechanical properties than alkaline and other heat treatment temperatures. At higher heat treatment temperatures (180 and 210°C), fiber bundles were destroyed by heat treatment and decreased fiber strength. This had an adverse influence on the reduction in mechanical properties of the composites. When fibers were heat-treated at higher temperatures, hemicellulose was significantly degraded, lignin was partially decomposed, and the cell wall structures were destroyed. The fiber bundles then became loose, resulting in decreased fiber strength.¹⁴ As shown in Figure 6(c,d), the random distribution of sisal fibers in the composites indicates a substantial portion of absorbent structure, which can absorb sound waves. There were many micro pores and continuous bubbles in the porous structure of the single sisal fiber bundle. When the sound wave was incident on the surface of the porous structure of sisal PLA composites, the air motion and compression in microspores caused by sound wave vibrations may have caused friction with the micro pore

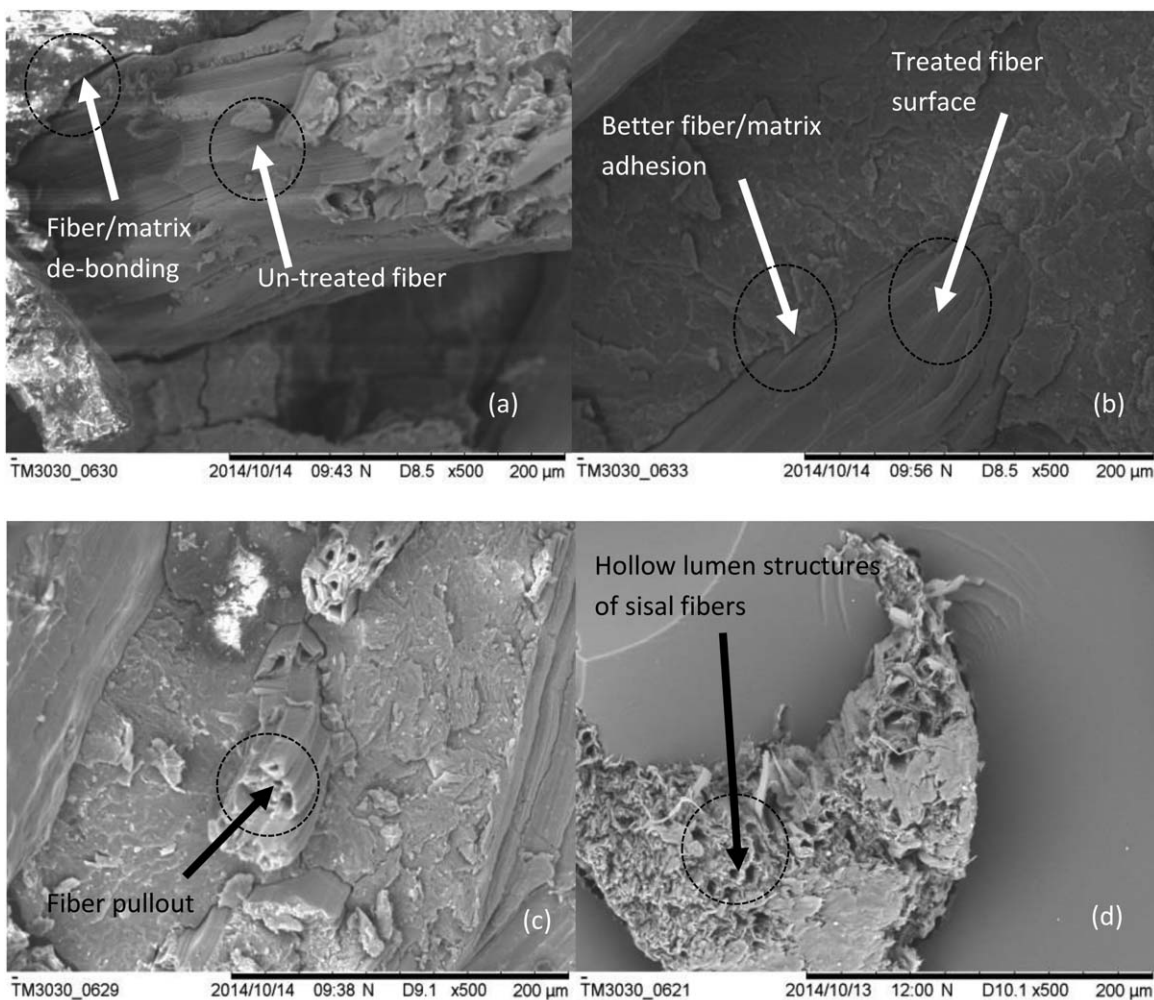


Figure 6. SEM micrographs of tensile fractured surfaces of (a) composites with untreated fibers; (b) composites with fiber treated with sodium hydroxide; (c) composites with fiber heat treated at 160°C; and (d) composites with fiber heat treated at 180°C.

wall. Due to the viscous forces and friction, there was a significant part of the sound energy that may have been converted to heat energy and caused sound energy attenuation.³² When the fiber loading increased to an optimum level, the sound waves hit the micro pores of the fiber bundle and strengthened the sound absorption property of the composites. The formation of special structures and the distribution were the main reason for

the acoustical absorptivity of natural fiber-reinforced polymer matrix bio-composites.

Effect of Fiber Loading on Sound Absorption Properties

Figure 7 shows the sound absorption coefficients of 30 wt % untreated sisal PLA composites at frequencies of 300–2000 Hz. It was observed that the sound absorption coefficients of the composites increased as the frequency was increased. Similar trends have been observed by Yang *et al.*³³ The sound absorption coefficients of composites with higher fiber loadings (20 wt %) were better than those with lesser fiber loadings. Jiang *et al.*³⁴ also found that with increasing seven-hole hollow polyester fiber content, a remarkable shift in sound absorption properties was observed, especially at higher concentrations.

From the SEM micrographs Figure 6(d), it was observed that a single sisal fiber was made up of a bundle of hollow sub-fibers that have lumen within them. This unique lumen structure of sisal fibers resulted in the lower density and higher porosity of their reinforcing PLA composites, which contributed to the added sound energy absorption, and therefore, a better acoustic absorption property.³⁵ The composites without filling sisal fibers

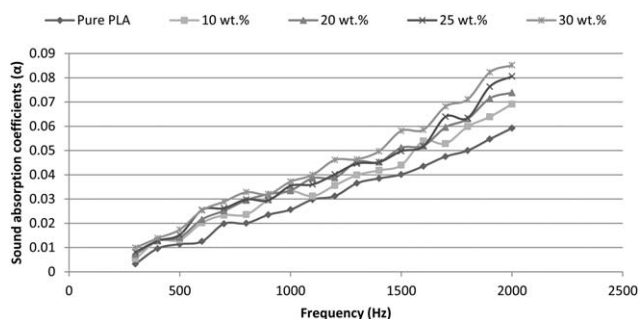


Figure 7. Effect of sisal content on the sound absorption performance of untreated PLA-sisal composites.

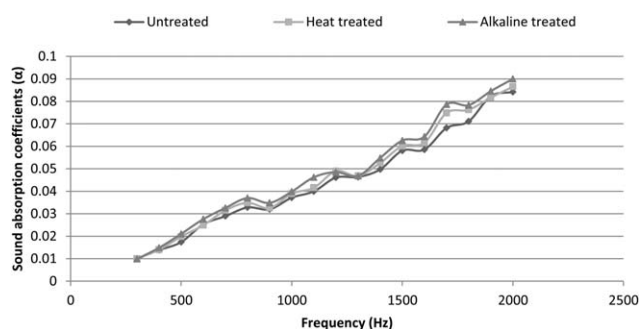


Figure 8. Effect of heat and alkaline treatment on the sound absorption performance of PLA-sisal composites.

are characterized by a low value of sound absorption coefficients. The structure of this composite is not typical for composites; in fact, it is only uniform matrix material without any filling and probably demonstrates sound reflection.³⁶ The addition of sisal fibers leads to a slight increase in value of sound absorption coefficient of the composites.

Effect of Heat and Alkaline Treatment of Fibers on Sound Absorption Properties

Figure 8 shows the results of sound absorption coefficients for untreated, heat and alkali treated fiber composites at 30 wt %. The effect of alkali treatment can be seen to increase the sound absorption coefficients. Among all the composite samples, alkaline treated showed the higher sound absorption performance with a sound absorption coefficient of 0.090 at the frequency of 2000 Hz, which was higher than that of the heat and untreated fiber composites with the coefficient of 0.087 and 0.085 Hz at 2000 Hz. An important microscopic parameter of a fiber is its diameter. The fiber diameter is directly related to the sound absorbing characteristics of the material.³⁷ Alkaline treatment alters the diameter of the fibers, causes the changes in sound absorption coefficients of the composites. It can also eliminate a large amount of hemicellulose and other impurities and produce a void and roughness on the fiber surface.³⁸ This could attribute to the fact that rough surface area of the fibers increases the friction between sound waves and the fiber which results in high sound absorption.

Fatima and Mohanty³⁹ confirmed that, alkali treatment enhances the mechanical and acoustical properties. Due to the removal of impurities from the fiber surface and separation of fiber stands. In the untreated fibers the lignocellulosic contents pectin, lignin, and hemicellulose and other low molecular weight materials can form a dense layer on the surface of sisal fibers, so the reflection is higher.³² The alkaline treatment removes the content of hemicellulose, pectin, and lignin from the fibers. This forms a porous structure on the surface of the fibers so the reflection is lower and the sound absorption is higher. This could be attributed to the different level of voids inside the composites, the inter-fiber micro-voids in the bamboo fiber could help efficiently absorb the sound energy while the inter air pockets in the composites will allow the sound wave pass through easily.⁴⁰

CONCLUSIONS

It can be concluded from the above analysis that chemical and thermal treatments change the functional groups on the surfaces

of the fibers, contributing to higher interfacial adhesion between the matrix and the fibers. The mechanical properties of the composites can, therefore, be effectively improved by appropriate heat treatment of the sisal fibers. Heat treatment at 160°C seemed to be the most desirable temperature in terms of strength and interface adhesion properties of sisal fibers. When the temperature was increased to 180°C and 210°C, the tensile, flexural, and impact properties decreased as a result of the degradation of fibers and PLA. Alkaline treatment also increased the strength and interfacial adhesion properties of the sisal fibers. The SEM micrographs revealed the lumen structures of the sisal fiber bundle and the distribution of sisal fibers in the PLA matrix. These special structures and the distribution were the main reason for better sound absorption. The thermal stability of heat-treated fibers was lower than that of chemically treated fibers. The thermal stability of the composites decreased when the sisal fiber content was increased in the composites. The results showed that an optimum temperature of 160°C removed strongly hydrophilic lignocellulosic components such as hemicelluloses from the fiber surface, and thus decreased the natural fibers' hydrophilicity, thereby improving adhesion between the fibers and the matrix.

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