Study of Sound Absorption Coefficients and Characterization of Rice Straw Stem Fibers Reinforced Polypropylene Composites

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In this study, both untreated rice straw stem fibers and fibers treated with sodium hydroxide were used. Maleic anhydride polypropylene (MAPP) was used to enhance adhesion of the fiber with the matrix. Composites were prepared with various combinations of fiber, ranging from 10 wt.% to 25 wt.%, and polypropylene in addition to 2 wt.% MAPP. These composites were then tested for acoustical, mechanical, thermal, infrared spectral, and morphological properties. The fibers were treated by being soaked in 5 wt.% NaOH solution at 30 °C for 30 min. The composites with treated fiber exhibited higher thermal stability, tensile strength, sound absorption, and fiber-matrix adhesion than the composites with untreated fiber. The results of sound absorption measurements showed that the composites with higher fiber content had better sound absorption than the composites with lower fiber content. The changes in the peaks in the Fourier transform infrared spectrum indicate that the alkaline treatment removed hemicellulose and lignin from the rice straw stem fibers.

Keywords: Sound absorption coefficients; Rice straw composites, Thermo-gravimetric analysis; Fourier transform infrared; Scanning electron microscopy

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INTRODUCTION

A composite material is the combination of two or more materials with distinct properties (Barbero 2011). The three core features that drive the use of composites are reduction of weight, reduction of part count, and resistance to corrosion. Additional advantages of composites that encourage its applications include resistance to wear, superior fatigue life, electromagnetic transparency, low thermal expansion, acoustical insulation ability, and high or low thermal conductivity (Malkapuram *et al.* 2009). Although composites have existed for a long time, the centuries-old growth of such composite development technology has not lost its drive. In fact, the search for such new materials has picked up steam lately, with a slight twist. With the heightened environmental awareness and ecological concerns, new rules and regulations require sustainable and eco-efficient technical applications. These changes have led to the escalation in the use of natural fiber reinforced plastics, replacing the conventional glass fiber reinforced plastics (Shubhra and Alam 2011). The extensive research and development of natural fibers as reinforcement in thermoplastic resin matrices have revealed that these fibers are economical, easily biodegradable, easily renewable, and nontoxic, in contrast with glass or carbon fibers. The five major advantages of using natural fibers over man made glass and carbon fibers are reduced energy consumption, low density, biodegradability, competitive specific mechanical properties, and low cost (Malkapuram *et al.* 2009).

Polypropylene, as a matrix material, has several outstanding characteristics for composite fabrication. These characteristics include flame resistance, high impact strength, dimensional stability, transparency, and high heat distortion temperature. Polypropylene is also appropriate for processes involving blending, filling, and reinforcing (Shubhra and Alam 2011). However, using lignocellulose fiber as reinforcement in polypropylene has its limitations. These limitations are due to its high polarity, relatively low thermal stability, degradation at high temperatures, fiber decomposition, and susceptibility to moisture (Gassan and Bledzki 1999; Bledzki and Faruk 2005; Pan *et al.* 2010). The highly polar characteristic of lignocellulose makes the fiber less compatible with non-polar polypropylene. Fiber degradation tends to occur when used with matrices that involve processing at high temperatures (Bledzki and Faruk 2005). Fiber decomposition leads to substantial fiber breakage, thus affecting the morphology and final properties of the composite. This usually occurs while bonding the fiber with the polymer matrix (Pan *et al.* 2010).

The high mechanical performance of composites relies on a strong adhesion between the hydrophilic natural fibers and the hydrophobic polymer matrix (Lee *et al.* 2008). Four surface modification methods for natural fibers were previously developed to enhance this adhesion. These methods include chemical, physical, physical-chemical, and mechanical treatments (Satyanarayana *et al.* 2009). Chemical modifications involve treatment with silanes or other chemicals. Chemical functionalization reactions help to enhance the natural fiber's hydrophobic nature, interfacial bonding between matrix and fiber, and surface roughness (George *et al.* 2001). Physical modifications involve treatment with plasma, corona, laser or γ-ray, and steam explosion. Mechanical modifications, such as rolling or swaging, may be used, but they may damage the fibers. Finally, physical-chemical modifications involve solvent extraction of surface gums and other soluble components of the fibers (Satyanarayana *et al.* 2009).

Recently, interest in agricultural waste as a substitute for wood-based raw materials has been growing. Among the various agricultural straws, rice straw is one of the most interesting materials that act as filler in polymer composites. It is known that rice straw possesses good thermal stability as compared with other agricultural waste (Buzarovska *et al.* 2008). Other examples can be seen based on Yang *et al.* (2003), whereas composite boards made of rice straw stem fiber along with wood particle-reinforced commercial urea formaldehyde showed higher sound absorption coefficients than particleboard, fiberboard, and plywood in the frequency range of 500 to 8000 Hz. Furthermore, commercial polyurethane reinforced rice straw and waste-tire particle composites were found to have higher sound absorption coefficients at frequencies within the range of 2000 to 8000 Hz than particleboard, fiberboard, and rice straw-wood particle composite board (Yang *et al.* 2004). Other than that, Egyptian rice straw reinforced polypropylene composites exhibited an increased Young`s modulus as maleic anhydride-grafted polypropylene fill grades were increased (Bassyouni *et al.* 2012). Wu *et al.* (2009) also managed to prepare the treated rice straw reinforced polypropylene composites with high intensity ultrasonication and coupling agent (MAPP) contents for testing tensile properties of the composites. However, no significant influence of MAPP content was observed on the tensile strength and the elongation at the breaking point of rice straw fibril polypropylene composites. The maximum Young's modulus value of 4 wt.% MAPP content was seen in the PP rice straw fibril composite.

In this research, the thermoplastic polymer polypropylene was used as the matrix material and a lignocellulose rice straw stem was used as the reinforcing material. The rice straw stem was used with and without sodium hydroxide treatment and the matrix was modified by maleic anhydride grafted polypropylene (MAPP). The treated and untreated rice straw stems were used to prepare fiber-reinforced composites. These composites were then used to examine the potential of using lignocellulose materials as sound absorbing applications. Thermo-gravimetric analysis (TGA) was used to determine the thermal decomposition of the composites. Fourier transform infrared (FTIR) helped to evaluate the interface compatibility. Morphological properties were analyzed using scanning electron microscopy (SEM). The sound absorption coefficients and tensile strength of the composites were evaluated using the two-microphone impedance tube method and a Universal Testing Machine (UTM).

EXPERIMENTAL

Materials

In this research, polypropylene pellets with the density of 0.9 g/cm^3, melt flow rate of 1.6 g/10min, at 230 °C, and repeat unit molecular weight 42.08 g/mol was supplied by Polypropylene Malaysia Sdn. Bhd was used as a matrix material. According to Tolinski (2011), polypropylene possesses tensile modulus that ranges from 1.1 to 1.5 GPa, tensile strength ranging from 25 to 33 MPa, elongation of 50 to 300% and crystallinity of 50% to 60%. The rice straw stem fiber consists mainly of carbohydrate components such as hemicellulose, cellulose, and lignin (Cheng *et al.* 2004). The rice straw stem fiber was obtained from local sources in Kota Samarahan, Sarawak, Malaysia. This variety of rice straw fibre had cellulose weight percentage of about 24% to 26%, hemicellulose weight percentage of approximately 24% to 28%, lignin weight percentage of 4% to 6% and residual ash weight percentage ranging from 8% to 16%.

Methods

Interface modifications of rice straw stem fibers-PP composites

The interfacial adhesion between natural fibres and polymer matrices has often been a vital issue in several natural fibres reinforced polymer matric composite systems. Natural fibres are amenable to chemical modification due to the presence of hydroxyl groups. The hydroxyl groups may be involved in the hydrogen bonding within cellulose molecules, thereby activating these groups or can introduce new structure that form effective interlocks within the system (John and Anandjiwala 2008). In this research sodium hydroxide (NaOH) with product code 'S/4920/AP1' was supplied by Fisher Scientific, UK. The pellet forms of sodium hydroxide completely soluble in water, high alkalinity and odourless was used to treat fibres. The rice straw stem fibers were washed with water to remove the adhered dirt. The fibers were treated with 5 wt.% sodium hydroxide solutions at room temperature for 30 min. They were then washed with distilled water until all sodium hydroxide was removed. Universal Indicator Solution supplied by Fisher Scientific, UK was used to make sure the fiber achieve it neutral pH. After washing, the fibers were dried in an oven at 70 °C for 5 h. After drying, they were cut with a laboratory blender to reduce the length of the fiber to between 1 and 10 mm.

Maleated polyolefin is a more effective method for modifying the natural fiber surface (Bledzki and Faruk 2005). The most popular maleated polyolefin is maleic anhydride polypropylene (MAPP), which was obtained by esterification between natural fiber hydroxyl groups and the anhydride functionality of MAPP through hydrogen bonding. The treatment of cellulosic natural fibers with MAPP copolymer provides covalent bonds across the interface. Through this treatment, the surface energy of the fibers is believed to be increased, thereby providing higher interfacial adhesion. In this research, the granulate form MAPP from Sigma Aldrich Co. with molecular weight of 9100 was measured using gel permeation chromatography (GPC) and viscosity 4.0 poise (190 °C), was measured using Brookfield Thermosel® was used. 2 wt.% of maleic anhydride grafted polypropylene was mixed with polypropylene in the mold.

Fabrication of composites

Treated and untreated rice straw stem fiber polypropylene composites were fabricated by a compression molding technique, using a 30 ton Hydraulic Hot Press LS-22071 (Lotus Scientific, Malaysia). This is a common method used in the wood-based panel industry. The rice straw stem fiber content and the average chopped rice straw stem fiber length in rice straw PP composites were 10 wt.%, 15 wt.%, 20 wt.%, and 25 wt.%, and 1 to 10 mm, respectively. Before mixing, the treated and untreated fibers were dried at 80 °C until all the moisture was lost. Polypropylene was uniformly mixed with rice straw stem fiber. It was then placed in 25 mm and 80 mm diameter stainless steel matched-die molds for sound absorption tests. Metal spacers were used to create different thickness of test specimens during fabrication that varied from 2 mm, 4 mm, and 6 mm for each diameter. The molding temperature was 180 °C with a holding time of 30 min. A pressure of 7 MPa was then applied for 20 min at 180 °C. The mold had a cross-sectional area of 72.5 mm^2 and thickness of 5 mm. While under the applied pressure for the tensile test, the molded composites were finally cooled down to room temperature. The composites obtained were conditioned in a standard testing atmosphere of 21°C to 24 °C and 65 % relative humidity for 24 h before testing.

Sound absorption test

The sound absorption coefficients of the composites were assessed using a small and large impedance tube setup with the two-microphone transfer function method, according to ASTM E1050-10 (2010). This setup was employed to measure different acoustical parameters in the range of frequency 500 to 6000 Hz. The measurement method required only the plane wave propagation to occur in the tube.

Thermal stability test

Thermo-gravimetric analysis (TGA) was conducted on the rice straw stem fiber-polypropylene composites to cover the spectrum for both untreated and treated fiber composites. The TGA was performed on a TA-60 WS workstation analyzer (Shimadzu Corp.; Kyoto, Japan) at a heating rate of 10 °C/min. Specimens were examined under flowing nitrogen (80 mL/min) over a temperature range of 30 to 900 °C.

Morphology test

The morphological studies of the chemically treated rice straw stem fibers were observed using a JEOL JSM-6390LA SEM (Tokyo Japan) with a field emission gun and an accelerating voltage of 5 kV, to collect images of the surface of composites. The test specimens were sliced and mounted on aluminum stubs with double-sided adhesive tape, and sputter coated with gold for 5 min to a thickness of approximately 10 nm under 0.1 torr and 18 mA to make the sample conductive.

Infrared spectroscopy (FTIR) test

The FTIR spectroscopy was performed using Shimadzu FTIR-8101 spectrometer in the range from 4000 cm^{-1} to 400 cm^{-1} and it was used to collect and understand the functional groups of lignocellulosic fibers and changes caused due to alkaline treatment. The sample pellets for FTIR spectroscopy included approximately 0.5 mg of powdered sample that was mixed thoroughly with approximately 100 mg of dried powdered potassium bromide in a small agate pestle. The mixture was placed in a die of specific dimensions. Pellets were made by applying vacuum pressure. The IR spectrum with all information about transmittance mode was obtained through IR solution software.

Mechanical test

The tensile testing was performed with a LS-28011-50 Universal Testing Machine (T-machine Technology Co., Ltd., Taiwan) according to ASTM D638-10 (2012).

RESULTS AND DISCUSSION

Sound Absorption

Figure 1 shows the results of the sound absorption coefficients of polypropylene rice straw stem fiber composites with varying fiber content at the frequencies from 500 to 6000 Hz. It was evident that fiber content influenced the sound absorption coefficients. The sound absorption capability of a given composite is characterized by the sound absorption coefficient (α). It is defined as the ratio of the acoustic wave energy absorbed by the composites to the total energy incident on the sample (Markiewicz *et al.* 2012). The sound was absorbed by converting sound energy to heat energy within the material, resulting in a reduction of the sound pressure. The sound absorption coefficients of composites increased as the frequency was increased. However, it decreased at certain frequencies and increased again. This decrease and increase in the behavior of the composites was due to the specific characteristic of rice straw reflecting sound at certain frequencies but absorbing sound in the other higher frequencies (Yang *et al.* 2003). The sound absorption coefficient of 25 wt.% fiber had a higher sound absorption coefficient compared to other fiber contents. With the increased amount of rice straw stem fiber content in the composite, a higher sound absorption coefficient was found, and the absorption peaked at 0.142. Jiang *et al.* (2012) reported that acoustic absorption of materials increased significantly with increasing seven-hole polyester fibre (SHPF) content. Markiewicz *et al.* (2012) also reported that sound absorption coefficients of PP crumble hemp plant composites, PP long flax fiber composites, PP-long hemp fiber composites, and PP rapeseed straw kaszub composites increased significantly with increasing fiber content in the middle and higher frequencies. The effect of alkali treatment can be seen to increase the sound absorption coefficients. An important microscopic parameter of a fiber is its diameter. The fiber diameter is directly related to the sound absorbing characteristics of the material (Arenas and Crocker 2010). Alkaline treatment alters the diameter of the fibers, causes the changes in sound absorption coefficients of the composites. 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 fibers, so the reflection is higher (Chen *et al.* 2010). The alkaline treatment removes the content of lignin, hemicellulose, and pectin 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.

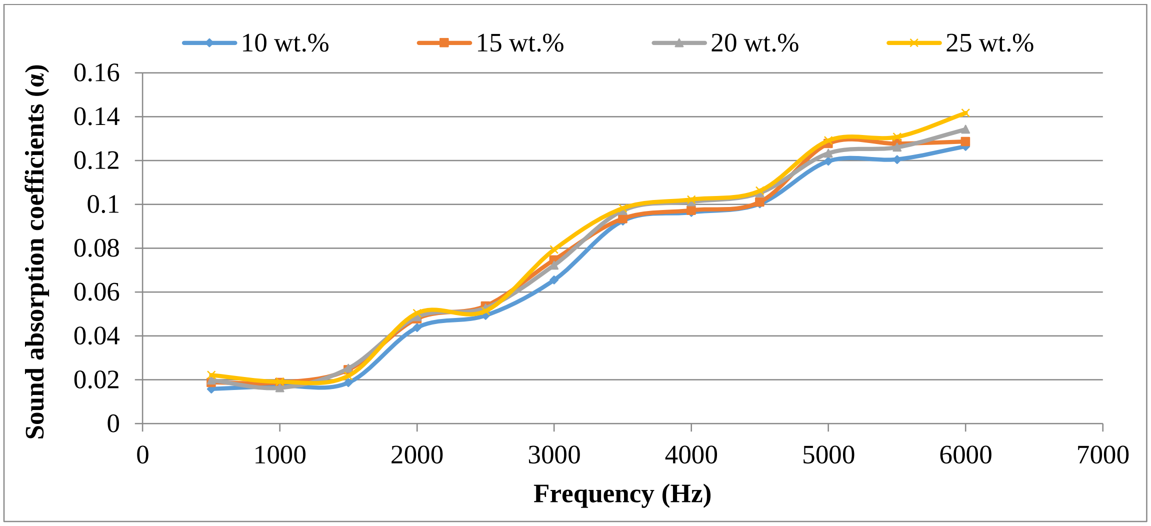

Fig. 1. Sound absorption coefficients of 4mm thick composites with various fiber loadings

As demonstrated in Fig. 2, the sound absorption coefficient was increased when thickness was increased. It can also be seen that the sound absorption coefficient increased when the frequency was increased. The sound absorption coefficient did not show significant difference within the range of 500 to 1500 Hz for the 2 mm, 4 mm, and 6 mm thicknesses. The effect of the thickness of the composites on absorption coefficient was apparent when the frequency range was between 2000 to 6000 Hz. This was possibly due to the increased porous nature of the composites.

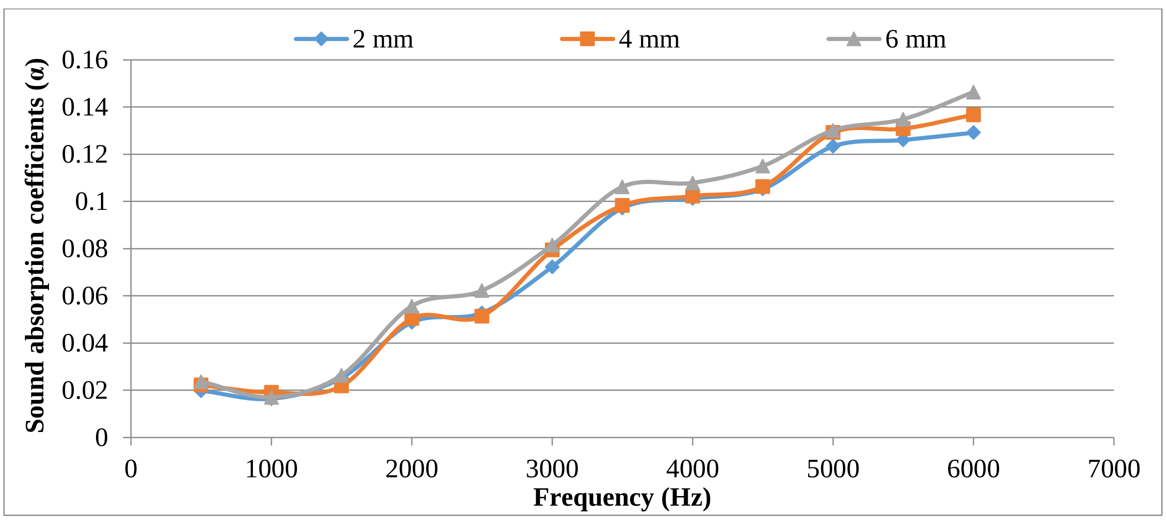

Fig. 2. Sound absorption coefficients of composites with different thickness

The 2 mm thick composites showed a steady increase in the sound absorption coefficient in the frequency range of 500 to 6000 Hz, with a maximum sound absorption coefficient of 0.126. The 6 mm thick composites showed the sound absorption coefficient of 0.147 at 6000 Hz. According to Rayleigh, for porous materials, material thickness enhances acoustic impedance (Huang *et al.* 2008). Fatima and Mohanty (2011) reported that natural rubber latex jute composites showed higher sound absorption coefficients for thick composites compared to thin composites. Jiang *et al.* (2012) reported that chlorinated polyethylene (CPE) and seven-hole polyester fibers (SHPF) composites show improved acoustic absorption with increasing composite thickness. Ersoy and Küçük (2009) reported that as the thickness of the sample was increased, a linear increase in sound absorption coefficient for the samples was observed.

Thermo-gravimetric Analysis

The results obtained by Thermo-gravimetric analysis (TGA) are presented in Fig. 3. Evaluation of the thermal stability of polypropylene rice straw stem fiber composites may be important in the determination of the limit of service temperature under environmental conditions. A typical TGA curve for composite thermal degradability implies that a sample subjected to heat first loses weight slowly and then sharply over a narrow range. Finally, as the reactant is exhausted, the curve returns to a slope of zero. In short, TGA curves were used to determine weight loss and to identify the decomposition of the material at a certain temperature (Azwa *et al.* 2013). Temperature plays a significant role in the dimensional stability of the natural fiber composites. Temperature causes direct thermal expansion or contraction, thus affecting the rate and the amount of moisture absorption which leads to fiber swelling (Wang *et al.* 2005).

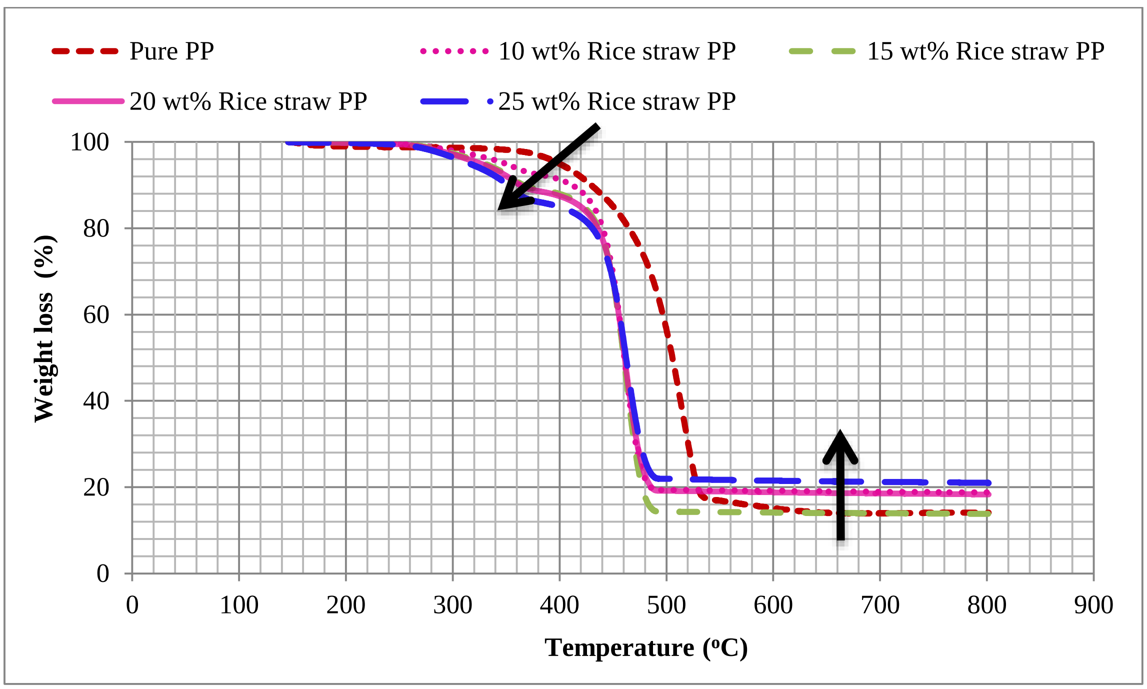

Fig. 3. TGA curves of pure polypropylene, polypropylene/rice straw stem fibers composites with various fiber loadings

The thermal degradation of pure polypropylene showed a one-step process that started at about 328 °C and ended at 515 °C, with a maximum rate at 488 °C and a mass loss about 99.3 wt.%. There was 0.7 wt.% residual mass at 550 °C. The PP rice straw stem fiber composites exhibited two steps of thermal degradation. The first step signified decomposition of biomass components, whereas the second step signified PP decomposition. The main gaseous products obtained from the thermal degradation of PP rice straw stem fiber composites were CO, H_2O, CO_2, formic acid, methane formaldehyde, methanol, and acetic acid (Părpăriţă *et al.* 2014a).

The initial weight loss took place below 100 °C and was due to the gradual evaporation of absorbed moisture. Further weight loss started at 275 °C and involved the decomposition of the major rice straw stem fiber components such as cellulose, hemicellulose, and lignin. Lignocellulosic constituents in the rice straw stem fibers were chemically activated and decomposed thermo-chemically between 150 to 500 °C. Hemicellulose, cellulose, and lignin decomposed between 150 to 350 °C, 275 to 350 °C, and 250 to 500 °C, respectively (Kim *et al.* 2004). It was observed that, upon increasing fiber content, the thermal stability of the composites decreased and the ash content increased. Hujuri *et al.* (2008) also observed a similar degradation pattern in composites. In short, the thermal stability of the composites decreased as the rice straw fiber content increased. The residual ash in the rice straw fiber (8 to 18 wt.%) was composed of 96 wt.% silica. The amount and distribution of silica in the rice straw is likely to be an important factor for determining the properties of the PP rice straw composites (Kim *et al.* 2004).

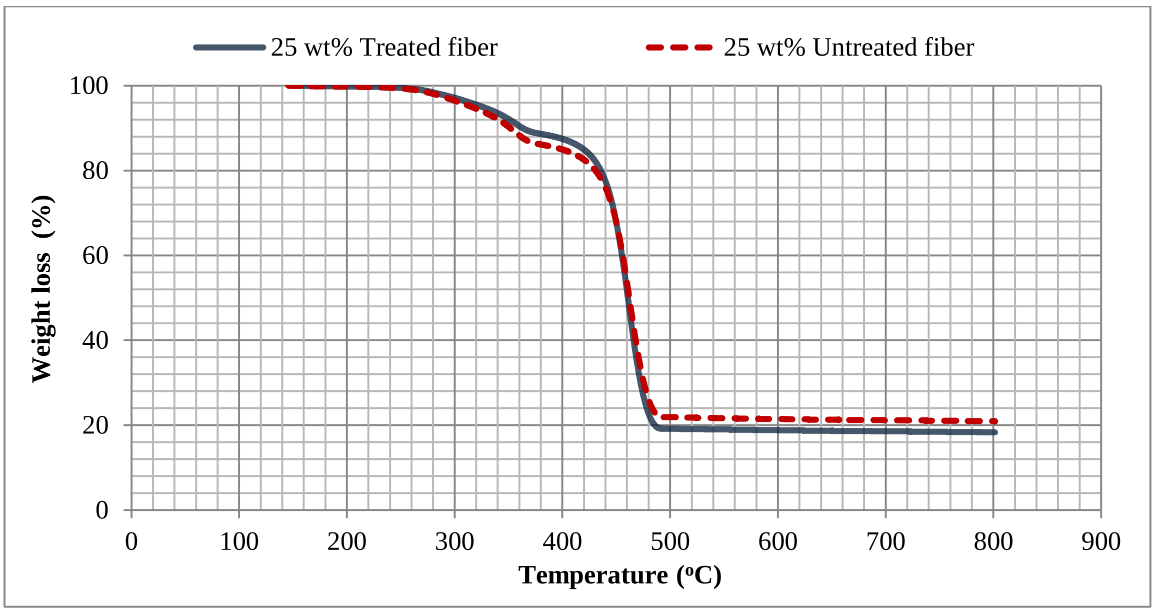

Fig. 4. TGA curves of untreated and alkaline treated fibers composites

Figure 4 shows the TGA curves for the untreated and the alkaline treated rice straw stem fiber polypropylene composites. The maximum decomposition temperatures for the composites with untreated and alkaline treated fibers were observed to be 470 °C and 486 °C respectively. A change in the degradation pattern of the composite was noticed after fiber incorporation. There was a marginal improvement in the thermal behavior of the composites after alkaline treatment of fibers, as evident in the Fig. 4. A similar study has been conducted by Mahato *et al.* (2013) that 5 to 15 % of alkali-treated coir fibers showed maximum thermal stability. Varma *et al.* (1986) investigated the effect of alkali treatment of natural fibers on thermal stability. Saha *et al.* (1991) reported that sodium hydroxide treatment of fibers leads to the formation of a lignin-cellulose complex which gives more stability to the fiber.

Fourier Transform Infrared (FTIR) Spectroscopy Test

Fourier transform infrared (FTIR) spectroscopy allowed the investigation of the surface modifications of fibers, the incorporation of coupling agents, and the modifications of the matrix. Investigations on these surface modifications or directly on the composite interface are important tools for establishing correlations between interface characteristics and composite properties. The FTIR spectra of the untreated and alkaline treated fibers composites are shown in Figs. 5. While treating the fiber with sodium hydroxide and adding MAPP in the PP matrix composites, the FTIR spectra showed prodigious changes. The algorithms reported several absorption bands commonly found in biomass at 3334.92 cm^{-1}, 2916.37 cm^{-1}, 1741.72 cm^{-1}, 1458.18 cm^{-1}, 1371.39 cm^{-1}, 1029.99 cm^{-1}, and 896.90 cm^{-1}. These absorption bands are associated with the presence of lignocellulosic components, such as cellulose, hemicellulose, and lignin (Sim *et al.* 2012). Cellulose is resistant to hydrolysis, strong alkali and oxidizing agents, but to some extent is degradable when exposed to chemical and solution treatments. Hemicelluloses are lower molecular weight polysaccharides that function as a cementing matrix between cellulose microfibrils. It is hydrophilic and can be easily hydrolyzed by dilute acids and bases (Azwa *et al.* 2013). Important spectral changes were seen in the 3500 to 1200 cm^{-1} spectral region. There was absorption of moisture in the untreated fiber at about 3334.92 cm^{-1}, which vanished in the alkaline treated fibers. This band 3334.92 cm^{-1} was attributed to the O-H stretching in H-bonded hydroxyls. The band located at 3334.92 cm^{-1} in untreated composite was shifted towards to the lower wavenumber for the degradation of PP rice straw stem composites as compared with treated composites. This indicates that rice straw is hydrophilic and easily absorbs water. This water absorption is demonstrated by the presence of active functional groups, such as carbonyl groups, from the spectrum at 2926.01 cm^{-1}.

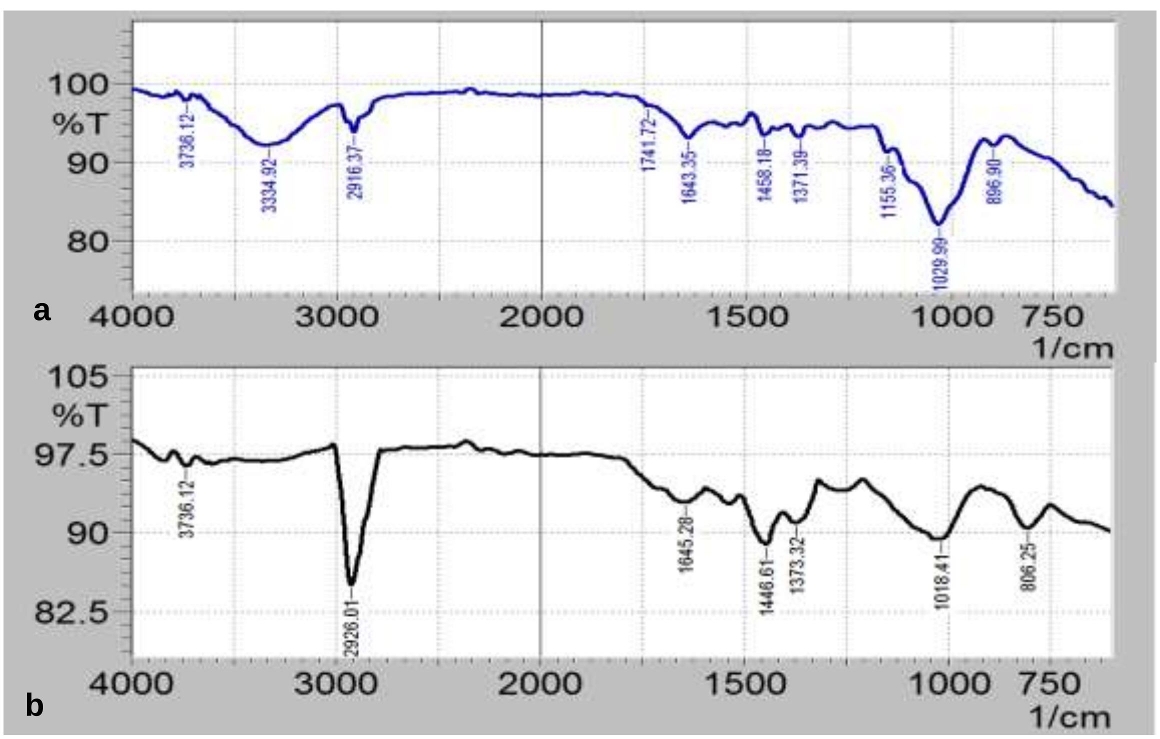

Fig. 5. FTIR spectra of (a) untreated and (b) alkaline treated rice straw stem fibers/PP composites

The bands at 2926.01 cm^{-1} and 1645.28 cm^{-1} showed asymmetric methylene stretching vibrations and conjugated C=O stretching vibrations of the carboxyl and acetyl groups in rice straw stem fiber (Bledzki and Faruk 2005). The peak band at 1741.72 cm^{-1} was attributed to the conjugated C=O stretching vibration of Ph-(C=O) group (lignin). This peak band was not present in the alkaline treated composites. The removal of lignin from the fiber surfaces caused this peak band to disappear. The band at 1458.18 cm^{-1} and 1371.39 cm^{-1} remarkably indicated the CH_3 asymmetric bending vibration in polypropylene, C-H deformation vibration in lignin, the CH_3 symmetric bending vibration in PP, and the CH deformation vibration in the carbohydrates.

The band at 1029.99 cm^{-1} demonstrated CH bending and wagging vibration, CH_3 rocking vibration in PP, and C-O and C-C stretching vibration in rice straw stem fiber. The CH_3 rocking, CH_2 wagging, and CH bending vibrations were seen at the 896.90 cm^{-1} absorbance band. The band at 806.25 cm^{-1} indicated the presence of CH_2 rocking and C-CH_3 stretching vibrations in PP and –CH_2 out of plane deformation vibration in the rice straw stem fiber (Bledzki and Faruk 2005). Changes in the position and intensity of these bands reflected a different type and yield of volatile products evolved during decomposition (Părpăriţă *et al.* 2014b). These studies confirmed the reduction of hemicellulose and lignin contents after fiber mercerization.

Mechanical Properties

Tensile tests were conducted on rice straw stem fiber-polypropylene composites to understand the effects of the fiber content, chemical treatments, and coupling agents (MAPP). The measurements were made at ambient conditions. The mechanical behavior of composites was greatly affected by the distribution and orientation of the reinforcing fibers, uniformity of lignocellulosic material spread in a polymeric matrix, the interface region, the nature of the fiber matrix interface, and the distribution and orientation of the reinforcing fibers (Singha and Thakur 2008). The interfaces played an important role in the physical and mechanical properties of natural fiber reinforced polymer matrix composites.

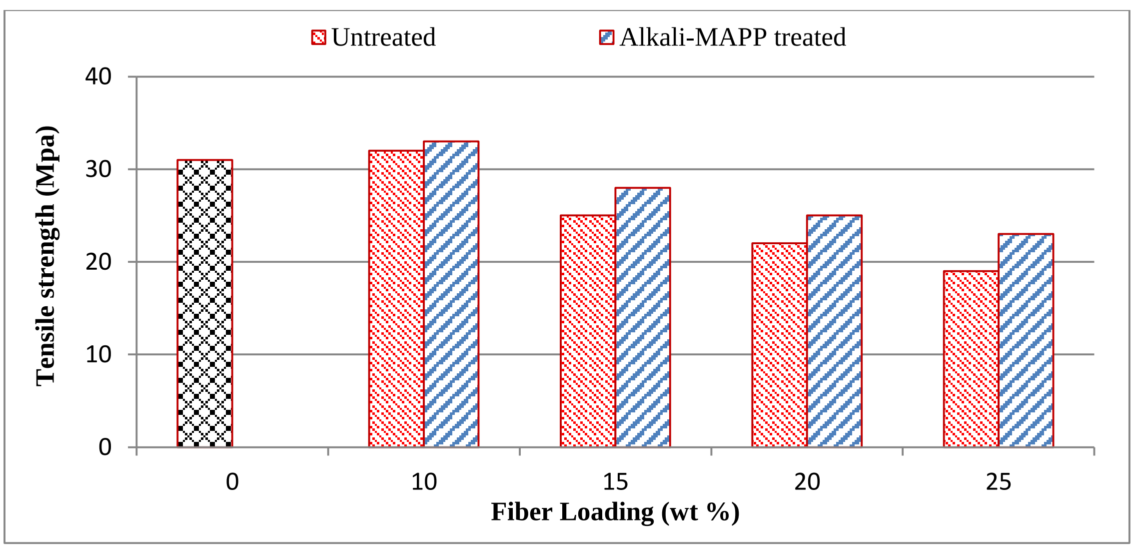

Fig. 6. Tensile strength of composites with various fiber loadings

The tensile strength of rice straw stem fiber-polypropylene composites with different fiber loadings is shown in Fig. 6. Among the composites tested, the tensile strength of 33 MPa was found to be highest at 10 wt.% rice straw. This value was also slightly higher than the value of pure polypropylene. The tensile strengths of the composites with alkaline-MAPP treated fiber were higher by 4% to 5% than the tensile strength of the composites with untreated fiber. This was an indication that surface treatment and coupling agents promote good fiber-matrix adhesion, allowing efficient stress transfer between the polymer and the natural fibers (Li *et al.* 2011). The fiber surface adhesive characteristics were improved by alkaline treatment, which removed natural and artificial impurities. This produced a rough surface. Due to alkaline treatment, fiber composites showed better tensile properties than untreated composites.

The tensile strength of the polypropylene-reinforced rice straw stem fiber, both treated and untreated composites, decreased when fiber loading increased. The addition of rice straw stem fiber from 15 wt.% to 25 wt.% resulted in a decrease in strength from 31 MPa for pure polypropylene to the range 28 MPa to 23 MPa. According to Ke and Sun (2000) and Ke *et al.* (2003), as the dispersed phase loading increases, the effective cross-sectional area of continuous phase is reduced, subsequently resulting in a decrease of tensile strength. The lowest value was 19 MPa for untreated 25 wt.% PP rice straw stem composites and 23 MPa for alkaline MAPP treated PP rice straw stem composites.

Similar observations were reported in other research studies of composites conducted by Demir *et al.* (2006). For both alkaline MAPP treated and untreated fiber composites, the reduction in tensile strength may be due to the weak interfacial interaction between the hydrophilic fiber and the hydrophobic polypropylene. This is because, as the filler loading increases, the interfacial area increases. This reduces the interfacial bonding between the fiber and the matrix, which further decreases the tensile strength (Premalal *et al.* 2002).

Morphology Study

The morphology of the fracture surface of untreated and treated rice straw stem fiber-polypropylene composites are presented in Fig. 7. Figure 7a shows some de-bonding between the fiber and matrix in the untreated composites, indicating that there was no bonding between the fiber and matrix. The alkalized composites showed improved fiber matrix interfacial adhesion. It was also observed that the layers of the matrix material were pulled out together with the fibers during fracture. This indicated better interfacial adhesion, and further supported higher mechanical properties of alkalized composites. Similar results were obtained by Pan *et al.* (2010) for wheat straw stem fiber polypropylene composites.

The SEM micrographs confirmed the chemical modification and its influence in the morphological aspects of fibers. Because of chemical modification, the mechanical and thermal properties were strongly influenced. Due to the alkaline treatment, the impurities present in the fiber surface were removed and the fiber strands were separated. This impurity removal and strand separation created a rough surface and affected both the mechanical and the sound absorption properties of the composites. Due to the porous nature of rice straw stem fiber, when the sound waves hit the surface of rice straw stem fiber PP composites, the non-vertical angle fiber with the orientation of the incident wave absorbed a part of the sound waves (Chen *et al.* 2010). For the short rice straw fiber, due to its random distribution in the composites, there was a considerable portion of porous structure, which absorbed the sound waves.

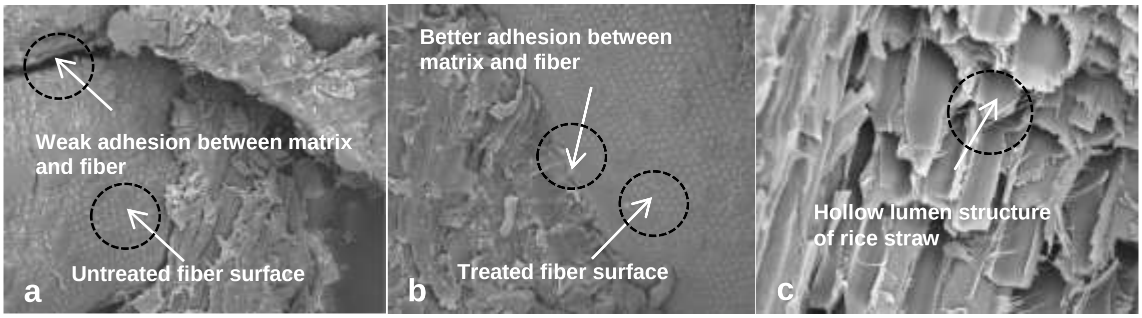

Fig. 7. SEM morphology of untreated and treated rice straw fiber polypropylene composites: (a) untreated, (b) alkaline MAPP treated, and (c) lumen structure of the fibers

CONCLUSIONS

1. The results of sound absorption coefficients measurements showed that the composites with higher fiber content and thickness exhibited higher sound absorption coefficients.
2. The alkaline treated fibers with MAPP improved interfacial adhesion between fiber and matrix, which improved the tensile strength and thermal stability of the composites.
3. Thermal stability of rice straw stem fiber reinforced polypropylene composites was lower than that of pure polypropylene. Similarly, as the fiber content increased in the composites, the thermal stability of the composites decreased and the ash content increased.
4. The morphological study showed better interfacial adhesion due to the effect of alkaline treatment-coupling agent on the rice straw and polypropylene composites. The FTIR analysis showed changes in the spectrum and the functional groups between the treated and untreated fibers.

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