

WOOD PLASTIC COMPOSITES MADE FROM CORN HUSK FIBER AND RECYCLED POLYSTYRENE FOAM

KOAY S. CHUN^{1,*}, NUR MUHAMMAD Y. FAHAMY¹,
CHAN Y. YENG², HUI L. CHOO¹, PANG MING M.¹, KIM Y. TSHAI³.

¹School of Engineering, Faculty of Innovation and Technology, Taylor's University,
Taylor's Lakeside Campus, No. 1 Jalan Taylor's, 47500, Subang Jaya,
Selangor DE, Malaysia

²Centre of Engineering Programmes, HELP University Fraser Technology Park Campus,
3.01, Level 1-7, Kompleks Metro Pudu, 1 Jalan Metro Pudu 2, Fraser Business Park,
55200 Kuala Lumpur, Malaysia

³Faculty of Engineering, University of Nottingham Malaysia Campus, Jalan Broga, 43500
Semenyih, Selangor, Malaysia

*Corresponding Author: seongchun.koay@taylors.edu.my

Abstract

This research is a preliminary study on the preparation of wood plastic composites (WPC) from corn husk fiber (CHF) and recycled polystyrene foam (rPS). The effects of fiber content and alkaline treatment on tensile, thermal, water absorption and morphological properties of the composites were investigated. The rPS/CHF composites were prepared using melt compounding and compression moulding processes. The results showed that an increase of fiber content increased the tensile strength, modulus, and thermal stability ($T_{d50\%}$) of composites. However, the water absorption of composites increased vastly as the fiber content increases. The addition of more fiber also caused an earlier thermal degradation to composites. Alkaline treatment has improved the tensile strength, modulus, thermal stability ($T_{d10\%}$), and also reduced water absorption of rPS/CHF composites. The WPS prepared from rPS and treated CHF shows better tensile and thermal properties with lower water absorption.

Keywords: Alkaline treatment, Corn husk fiber, Natural fiber composites, Recycled polystyrene.

1. Introduction

Wood-plastic composite (WPC) is a combination of wood waste and plastics material [1]. WPC is an alternative way of reusing sawing wood and plastics and the fiber raw materials can be collected from plywood mills, sawmills and wood product mills [2]. In addition, being the fastest growing and largest market make the demand on WPC to be high [3, 4]. Besides, WPC have many applications ranging from industrial products to commercial building and home construction, such as fencing in construction, cladding and decking [5, 6]. Previously, WPC was made from wood fiber and plastic materials but now WPC can be made from natural fiber obtained from agricultural waste and recycled plastic materials. Thus, WPC is considered as a sustainable material because it is made from recycled plastic and agricultural waste materials [7].

Nowadays, natural fibers made from agricultural waste are widely used in WPC industry. This is because natural fibers exhibit similar properties as compared to wood fiber, but are lower in cost and more eco-friendly as utilizing the waste material [8, 9]. In Malaysia, natural fiber can be obtained from many of types of agricultural by-products and crop wastes for example, rice husk [10], coconut shell [7-9], palm oil empty fruit bunch [11], durian husk [12], and corn cobs [13]. Presently, natural fibers are widely used in almost everywhere in modern industries from construction material to automotive part [14]. One example of famous WPC product that can be found in the market today is the IKEA's ODGER chair, which was made from recycled plastic and wood flour composite through injection-moulding process [8].

Corn or maize is the most widely planted crop in the world. Corn husk is the leafy shell covering the corn. In general, corn husks are the leftovers after the corns were harvested and corn husk is the non-food part of the corn and it is usually left as waste material in corn field. The corn husk waste accumulated to about 45 million tons per year in the whole world. In addition, corn husk consists a high content of lignocellulosic fiber (e.g., 1.9% protein, 2.8% ash, 6.6% lignin, 38.2% cellulose, and 44.5% hemicellulose) [15]. Besides, corn husks fibers also show an outstanding strength, high elongation, good pliability, moderate durability and ready biodegradability. The fiber obtained from corn exhibited a specific strength and specific modulus of 2.7 tenacity/g den⁻¹ and 70 modulus/g den⁻¹, respectively [16]. For this reason, corn husks can be utilized as natural fibers in WPC.

Polystyrene is a thermoplastic mostly used for storage and packaging in food industry. It is also used in other industries such as foam, appliances and automotive industry. Polystyrene foam, also known as expanded polystyrene, has many advantages such as light weight, low cost, moisture resistance, high energy absorbing efficacy and good heat insulator [17]. Thus, polystyrene foam is widely used in industry for packaging. It is reported that more than 1000 tons of polystyrene foam were disposed into the environment as waste material and the amount is increasing annually [18]. Polystyrene foam is seldom recycled because it is made of 98% air and has high size to weight ratio [19]. Recycling rate of polystyrene foam is low, due to its bulk, polystyrene foam takes up storage space and costs more to transport and yet yields only a small amount of polystyrene for re-use or remolding. Most of the time, polystyrene foam will end up as landfills and it easily fill up the landfill site in a short time since it is non-biodegradable [20]. Thus, the present research is underway to recycle the polystyrene foam as raw material to produce WPC.

This research is a preliminary study on preparing WPC from recycled polystyrene foam and corn husk fibers. The studies focus on the effects of fiber content and alkaline treatment on tensile, thermal, morphological and water absorption properties of the composite.

2. Methodology

2.1. Materials

Polystyrene foam is mainly used as packaging material for electrical appliances. Thus, the disposed polystyrene foam was collected from electrical shops. Corn husks were obtained from wet market. The chemicals used in this experiment, such as sodium hydroxide (NaOH) and acetone were supplied by Evergreen Engineering & Resources, Malaysia.

2.2. Preparation of recycled polystyrene

Firstly, the polystyrene foams cleaned from any contaminate. Then, it was cut into small pieces and dissolved in acetone solvent. The dissolute polystyrene foam was filtered and placed in an oven at 70°C to remove remaining acetone. After dried, the recycled polystyrene (rPS) was in solid piece. Last, the rPS was cut into smaller pieces and stored for further process.

2.3. Preparation of corn husk fiber

First, the collected corn husks were washed to remove any dirt and then cut into small pieces. Next, they were dried in oven at 70°C until fully dried. The dried corn husks were further ground into smaller short fibers using a grinder. The corn husk fibers (CHF) were sieved using 100 mesh stainless steel sieve to obtain homogenous size of short fibers. Part of the CHF was further treated with sodium hydroxide (NaOH) solution using method suggested by Reddy and Yang [16]. The CHF were immersed in 1 mole of NaOH solution for 1 hour at 24 °C. Then, treated CHF were filtered and washed using distilled water until the pH became neutral. Lastly, the treated CHF were dried in oven at 70°C until fully dried.

2.4. Preparation of composites

The rPS and treated/untreated CHF were compounded using Haake Rheomix 600p (Brand: Thermo Fisher Scientific Inc., USA) at a temperature of 190°C and a rotor speed of 80 rpm. The composites were prepared with fiber content of 30, 40, 50, and 60 weight percentage (wt%). The total mixing time was 8 min. Then, the compounds were moulded into sheet form using hot press machine (model: Moore, Taiwan) at temperature similar to the compounding process and the pressure used was 100 kPa. The thickness of the composite sheet was 1 mm. The operating steps included: i) preheat the compound for 4 minutes, ii) fully compress the compound for 1 minute, iii) cool the specimen to temperature below 50°C, iv) remove the composite sheet from mold. The composite sheet was cut into tensile specimens and the dimensions of the tensile specimens were following ASTM D638 standard.

2.5. Testing and analysis

Tensile test of rPS/CHF composites were carried out following ASTM D638 standard. The composites were tested for tensile properties using an Instron

universal testing machine (model 5596, USA). A 15 kN load cell and cross-head speed of 5 mm/min were used. A minimum of 7 specimens were tested for each formulated composite.

The selected fracture rPS/CHF specimens were used for morphological studies using scanning electron microscope (SEM), Model: FEI Quanta 400F, Thermo Fisher Scientific Inc., USA. The specimens were coated with thin layer of palladium before examination. The beam energy used in this experiment was 10kV.

Thermal analysis of untreated and treated rPS/CHF composites at selected fiber content were studied using thermogravimetric analysis (TGA), brand: PerkinElmer, USA. The weight of the specimen for TGA was about 5-7 mg. The specimens were undergone thermal scan at a heating rate of 10°C/min and range of thermal scan from 30°C to 700°C under nitrogen atmosphere. The nitrogen gas flow rate was fixed at 20 mL/min. Then, the weight loss against the temperature data were obtained from TGA.

Water absorption test of rPS/CHF composites were performed according to ASTM D570 standard. All rPS/CHF composites samples with dimensions 30 mm x 25 mm x 2 mm were immersed in distilled water at room temperature. The water absorption was determined by recording the weight change after immersed in distilled water at times 25, 50, 200, 400 and 900 hours. A mass balance with the precision of ± 1 mg was used to measure the sample weight. The percentage of water absorption (W_a) at time (t) were calculated using Equation 1, where W_d and W_n are the original dried sample weight and weight of the sample after absorbing water, respectively.

$$W_a = \frac{W_n - W_d}{W_d} \times 100\% \quad (1)$$

In addition, Fourier transmission infra-red spectroscopy (FTIR) was used to characterize untreated and treated CHF. The FTIR spectra of specimens were recorded with 32 scans for more precise average reading, in the wavenumber range from 4000-600 cm^{-1} . A resolution of 4 cm^{-1} was used for the FTIR analysis.

3. Results and Discussion

3.1. Tensile properties

Figure 1(a) shows the tensile strength of untreated and treated rPS/CHF composites. The results show that increasing fiber content increased the tensile strength of the composites. Comparing to literature, natural fiber composites typically exhibit a higher tensile strength compared to conventional plastic materials [21]. Thus, addition of natural fibers that enhanced the strength of composites was also reported in many literatures [22, 23]. Besides, the mechanical strength of composites is usually influenced by several factors, including interfacial bonding, aspect ratio of fiber, and fiber orientation [21]. In this case, the CHF used in this research was short fibers and it was randomly orientated. In general, fibers orientated either parallel or perpendicular to direction of applied stress would have opposite mechanical behavior. Fibers aligned parallel to the direction of stress normally contributed higher tensile strength to composites. On the other hand, fibers oriented perpendicularly to the direction of stress would reduce the tensile strength of the composites dramatically. The amount of fibers that are parallel to the applied stress would increase as the fiber content increases. Thus, the rPS/CHF composites show an increment in tensile strength when added with more fiber. The tensile modulus of rPS/CHF composites

also increased with increasing fiber content, as illustrated in Fig. 1(a). In general, natural fiber has higher modulus compared to plastic materials [21]. Hence, the presence of CHF that increased the modulus of composites was as expected [24, 25]. Furthermore, the chain mobility of rPS matrix was restricted by the presence of friction between fiber and matrix. This is another reason the rPS/CHF composites with higher fiber content exhibited high tensile modulus.

Figure 1(b), the tensile results also show that the treated rPS/CHF composites exhibited higher tensile strength and modulus as compared to untreated rPS/CHF composites. After treatment, the strength and modulus of rPS/CHF composites have improved on average by 26% and 13%, respectively. Alkaline treatment has removed part of lignin, hemicellulose and other components from CHF and it increased the surface roughness of the fibers. The interfacial interlock was improved between treated fibers and rPS matrix. For this reason, the stress transfer between fiber-matrix was improved with stronger interfacial interlock and yielded composites with higher strength and modulus. Similar observations was also reported in other literature [26, 27].

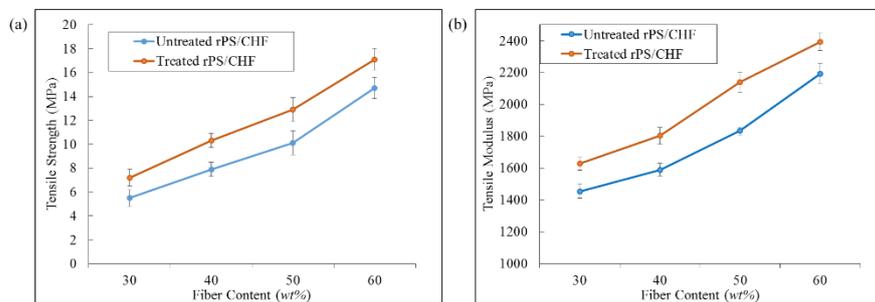


Fig. 1. (a) Tensile strength and (b) Tensile modulus of rPS/CHF composites with different fiber content.

3.2. Water absorption

The water absorption results of untreated and treated rPS/CHF composites are displayed in Fig. 2. The water absorption of rPS/CHF composites was significantly increased as the fiber content increases. The CHF naturally absorbs water because the chemical structure of cellulose, hemicellulose and lignin consist plenty of hydroxyl groups. Thus, the hydroxyl groups from fiber can easily form hydrogen bond with water molecules [7]. Figure 3 shows that water molecules were able to diffuse into composite and were trapped in micro gaps present between fiber and matrix. The micro gap at interfacial region was due to poor adhesion between fiber and matrix. Therefore, the increase of fiber content increased the water uptake of composites. This finding is also in agreement with other researchers, such as Penjumras et al. [27]. Alkali treatment significantly reduced the water absorption of rPS/CHF composites. From Fig. 4, the water absorption of treated rPS/CHF composites is on average 29% lower as compared to untreated rPS/CHF composites. As mentioned earlier, the addition of treated CHF has better adhesion with rPS matrix. The gaps between treated CHF and rPS matrix became narrower. Thus, less water molecules were trapped in the interfacial region. Previous studies by the Chun et al. [25, 28] also found that composites with treated natural filler would have lower water absorption

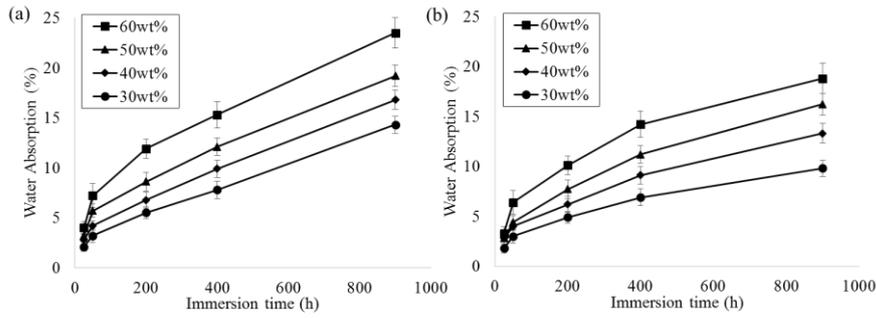


Fig. 2. Water absorption against time curves of (a) untreated and (b) treated rPS/CHF composites.

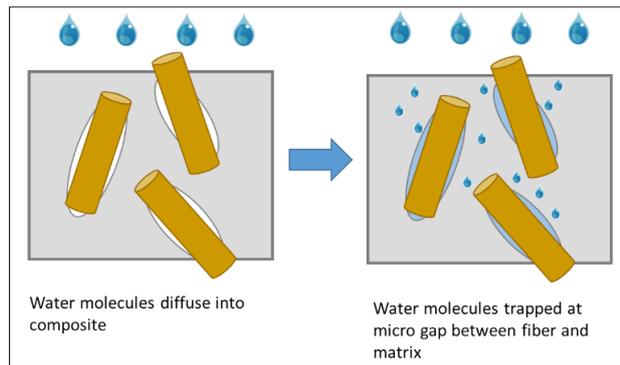


Fig. 3. Water molecules trapped at fiber-matrix interface.

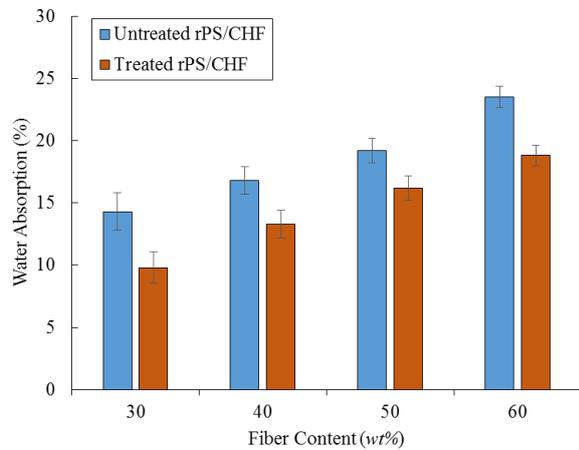


Fig. 4. Water absorption of untreated and treated rPS/CHF composites at 900 hours immersion time.

3.3. Morphological Properties

Figures 5(a) and (b) show the SEM micrographs of untreated rPS/CHF composites at selected fiber content. There are small gaps found between fiber and the matrix. This indicates that the CHF has poor adhesion with rPS matrix. This finding also

supported the explanation for water absorption because these gaps were the region where water molecules were trapped in the composites. Regarding to Fig. 5(b), several holes caused by fiber pull out can be observed. This observation also indicated that part of the fibers are aligned in parallel to the direction of the applied stress, but the fiber was weakly bonded to the matrix. Thus, it pulled out from the matrix forming a hole. The SEM micrographs of treated rPS/CHF composites are illustrated in Fig. 6. The gaps that can be found between the fiber and the matrix was reduced. In addition, no fiber pull out was observed. Some of the fibers were found to be embedded and fully covered by the matrix. This evidenced that the treated CHF have better adhesion with rPS matrix.

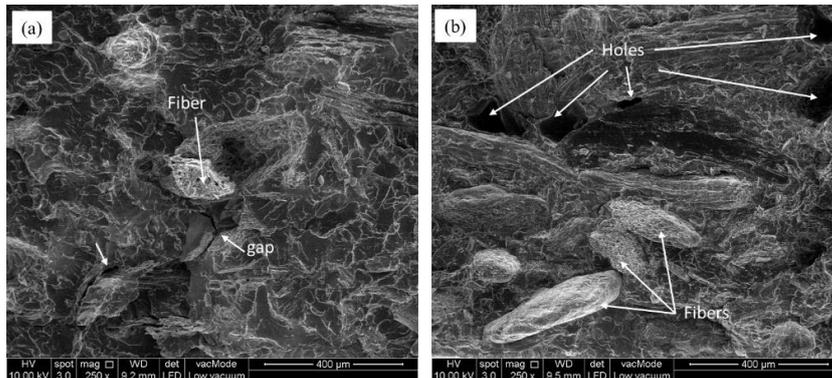


Fig. 5. SEM micrographs of untreated rPS/CHF composites with (a) 40 wt% and (b) 60 wt% of fiber content.

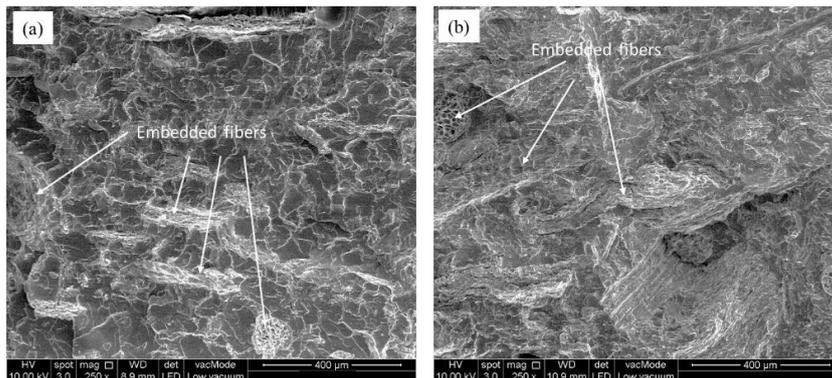


Fig. 6. SEM micrographs of treated rPS/CHF composites with (a) 40 wt% and (b) 60 wt% of fiber content.

3.4. Thermal properties

Figure 7 displays the TGA curves of untreated and treated rPS/CHF composites at selected fiber content. The residue weight at 700°C, decomposition temperature at 10% ($T_{d10\%}$) and 50% ($T_{d50\%}$) obtained from TGA curves are listed in Table 1. The results show that the $T_{d10\%}$ of rPS/CHF composites decreased as fiber content increases. The major component of CHF is cellulose and it typically decomposes at temperature above 350°C. However, CHF also consists of minor components such as hemicellulose and lignin, which have lower thermal stability and start to

decompose at temperature above 250°C. Thus, the untreated rPS/CHF composites exhibited earlier thermal degradation and it was more obvious when fiber content was increased. This earlier thermal degradation is attributed to the thermal decomposition of moisture, volatile compounds, and hemicellulose in CHF. On the other hand, the $T_{d50\%}$ of untreated rPS/CHF composites raised with additional fiber. In general, polystyrene is a thermoplastic comprised of plenty of aromatic molecules in a structure, which promotes the char yield of composite [29].

Besides, the natural fiber itself also contains many aromatic molecules that can be found in lignin. Lignin also contributed to char during thermal decomposition process [7]. The weight residue is the char left after thermal decomposition of composites. From Table 1, the char residue of composites also increased with increasing of fiber content. The char usually acts as thermal barrier for the composite that can improve thermal stability [8, 9]. Hence, the composites with higher fiber content usually show higher thermal stability at temperature above 400°C. Similar observation was found in composites with other types of natural fibers [30, 31].

Table 1. TGA data of untreated and treated rPS/CHF composites at selected fiber content.

Composites	$T_{d10\%}$ (°C)	$T_{d50\%}$ (°C)	Residue weight (%)
Untreated rPS/CHF:60/40	272	441	8.80
Untreated rPS/CHF:40/60	268	433	9.60
Treated rPS/CHF:60/40	319	422	6.40
Treated rPS/CHF:40/60	309	409	7.10

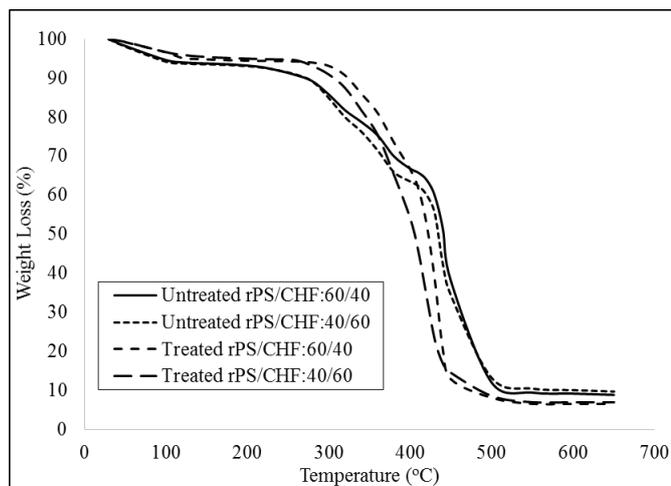


Fig. 7. TGA curves of untreated and treated rPS/CHF composites at selected fiber content.

The treated rPS/CHF composites show higher $T_{d10\%}$ compared to untreated rPS/CHF composites. As discussed before, most of the hemicellulose and lignin were removed from CHF during the alkaline treatment. Moreover, the treated rPS/CHF

composites also have less water absorption due to the improved interfacial adhesion and weight loss due to the removal of water molecules was also reduced. Thus, the treated rPS/CHF composite has better thermal stability at temperature below 300°C. However, the $T_{d50\%}$ of rPS/CHF composites was reduced after alkaline treatment. This is because most of the lignin was removed after alkaline treatment and the amount of char generated during the thermal degradation was reduced. As can be observed from Table 1, the char residue of treated rPS/CPH composites was decreased. For this reason, the thermal protection effect of char residue also reduced and thermal stability of treated rPS/CPH composites at temperature above 400°C also reduced.

3.5. FTIR analysis

Figure 8 illustrates the FTIR spectrum of untreated and treated CHF. For untreated CHF, the wide peak recorded at 3381.5 cm^{-1} was due to the stretching of O-H, which belongs to hydroxyl groups in fiber [12]. In the 3000-2800 cm^{-1} range, the peaks were caused by the stretching of C-H. Peak measured at 1727.1 cm^{-1} is related to ester carbonyl vibration in lignin [7, 8]. As can be seen the intensity of the peak has reduced and the peak value shifted from 1727.1 to 1714.6 cm^{-1} . This is because after the alkaline treatment, part of lignin has been removed from CHF. Then, carbonyl group in hemicellulose and carbonyl aldehyde in lignin were represented by the peak at 1638.4 cm^{-1} [9]. After treatment, the peak shifted from 1638.4 to 1641.5 cm^{-1} and the peak intensity was slightly reduced. This indicated the contents of hemicellulose and lignin were also decreased. The peaks at 1427.5 cm^{-1} was attributed to CH_2 stretching from cellulose, while the peaks at 1370.4 cm^{-1} and 1320.5 cm^{-1} were assigned to C-H group vibration from cellulose [13]. The C-O groups from acetyl group of lignin found at peak 1245 cm^{-1} [28]. The intensity of the peak at 1245 cm^{-1} reduced which indicated that some of the lignin has been removed during the alkaline treatment. The broad peak ranging from 1000 to 1150 cm^{-1} corresponds to the anti-symmetrical vibration of C-O-C groups from cellulose. The last peak at 903.18 cm^{-1} was due to C-H stretching of lignin [26]. After alkaline treatment, the peak shifted from 903.18 cm^{-1} to 894.27 cm^{-1} . This is also evidence that the part of the lignin was removed from CHF.

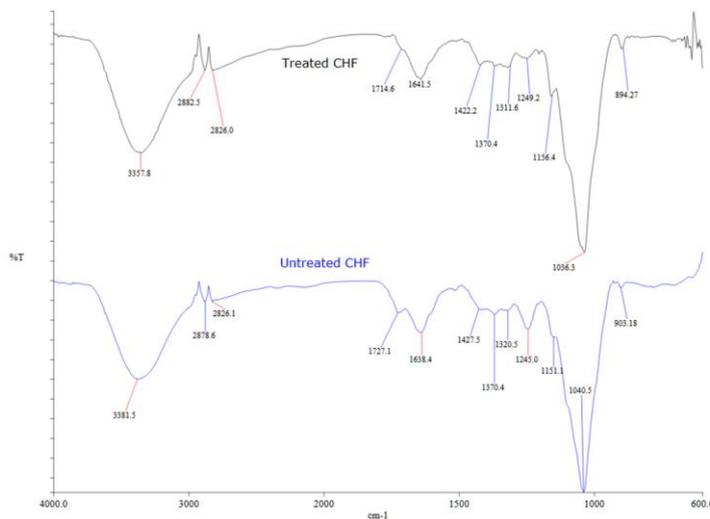


Fig. 8. FTIR curves of untreated and treated CHF.

4. Conclusions

In short, the tensile strength and modulus of rPS/CHF composites increased with the increase of fiber content. The addition of more fibers has increased the water absorption and contributed to earlier thermal degradation of rPS/CHF composites. However, the presence of more CHF caused char formation effect to composites, which lead to, increased thermal stability at higher temperatures. FTIR analysis also evidenced that part of hemicellulose and lignin have been removed from CHF after the alkaline treatment. After the treatment, tensile strength and modulus of the composites were significantly improved and water absorption was reduced. The SEM results also evidenced that the fiber-matrix adhesion was improved due to alkaline treatment. The treated rPS/CHF composites with 60 wt% of fiber shows tensile strength of 17 MPa and modulus of 2390 MPa, The strength is yet to reach similar level as commercial WPC, such as WPC made from rice husk owning tensile strength of 25 MPa, however, rPS/CHF is a potential WPC if further modified with coupling agent. Besides, the thermal stability of treated fiber against thermal degradation was improved, and thus, the effect of earlier thermal degradation on treated composites was reduced. Then, the thermal stability of composites at high temperature was reduced. However, it is more important to improve the thermal stability of composites against earlier thermal degradation, because composites are usually processed within the temperature 180°C to 250°C.

Nomenclatures

$T_{d10\%}$	Decomposition temperature at 10% weight loss
$T_{d50\%}$	Decomposition temperature at 50% weight loss
t	Time
W_a	Water absorption at time (t)
W_n	Original dried sample weight
W_d	Sample weight after water absorption
wt%	Weight percentage

Abbreviations

ASTM	American Society for Testing and Materials
CHF	Corn Husk Fiber
FTIR	Fourier Transmission Infra-Red
NaOH	Sodium Hydroxide
rPS	Recycled Polystyrene
SEM	Scanning Electron Microscope
TGA	Thermogravimetric Analysis
WPC	Wood Plastic Composites

References

1. Chun, K.S.; Subramaniam, V.; Yeng, C.M.; Meng, P.M.; Ratnam, C.T.; Yeo, T.K.; and How, C.K. (2018). Wood plastic composites made from post-used polystyrene foam and agricultural waste. *Journal of Thermoplastic Composite Materials* (in press).
2. Butylina, S.; Martikka, O.; and Kärki, T. (2011). Physical and mechanical properties of wood-polypropylene composites made with virgin and/or

- recycled polypropylene. *Polymer Plastic Technology Engineering*, 50(10), 1040-1046.
3. Pilarski, J.M.; and Matuana, L.M. (2005). Durability of wood flour-plastic composites exposed to accelerated freeze-thaw cycling. Part I. Rigid PVC matrix. *Journal of Vinyl Additives and Technology*, 11(1), 1-8.
 4. Gurunathan, T.; Mohanty, S.; and Nayak, S.K. (2015). A review of the recent developments in biocomposites based on natural fibres and their application perspectives. *Composites Part A*, 77, 1-25.
 5. Bajwa, S.G.; Bajwa, D.S.; Holt, G.; Coffelt, T.; and Nakayama, F. (2011). Properties of thermoplastic composites with cotton and guayule biomass residues as fiber fillers. *Industrial Crops and Product*, 33(3), 747-755.
 6. Carroll, D.R.; Stone, R.B.; Sirignano, A.M.; Saindon, R.M.; Gose, S.C.; and Friedman, M.A. (2001). Structural properties of recycled plastic/sawdust lumber decking planks. *Resources, Conservation and Recycling*, 31(3), 241-251.
 7. Chun, K.S.; Husseinsyah, S.; and Azizi, F.N. (2013). Characterization and properties of recycled polypropylene/coconut shell powder composites: effect of sodium dodecyl sulfate modification. *Polymer Plastic Technology and Engineering*, 52(3), 287-294.
 8. Chun, K.S.; Husseinsyah, S.; and Osman, H. (2013). Properties of coconut shell filled polylactic acid ecomposites: effect of maleic acid, *Polymer Engineering and Science*, 53(5), 1109-1116.
 9. Chun, K.S.; Husseinsyah, S.; Osman, H. (2012). Mechanical and thermal properties of coconut shell powder filled polylactic acid biocomposites: effects of the filler content and silane coupling agent. *Journal of Polymer Research*, 19(5), 1-8.
 10. Yang, H.S.; Kim, H.J.; Son, J.; Park, H.J.; Lee, B.J.; and Hwang, T.S. (2004). Rice-husk flour filled polypropylene composites: mechanical and morphological study. *Composites Structure*, 63(3-4), 305-312.
 11. Zailuddin, N.L.I.; Husseinsyah, S. (2016). Tensile properties and morphology of oil palm empty fruit bunch regenerated cellulose biocomposite films. *Proceeding of Chemistry*, 19, 366-372.
 12. Jason, Y.M.W.; and Chan, M.Y. (2017). Influence of bleaching treatment by hydrogen peroxide on chitosan/durian husk cellulose biocomposite films. *Advances in Polymer Technology* (In Press).
 13. Yeng, C.M.; Husseinsyah, S.; Ting, S.S. (2013). Chitosan/corn cob biocomposite film by cross-linking with glutaraldehyde. *Bioresources*, 8(2), 2910-2923.
 14. Soury, E.; Behraves, A.H.; Esfahani, E.R.; and Zolfaghari, A. (2009). Design, optimization and manufacturing of wood-plastic composite pallet. *Material & Design*, 30(10), 4183-4191.
 15. Barl, B.; Biliaderis, C.G.; Murray, E.D.; and Macgregor, A.W. (1991). Combined chemical and enzymic treatments of corn husk lignocellulosic. *Journal of Science Food and Agriculture*, 56(2), 195-214.
 16. Reddy, N.; and Yang, Y. (2005). Properties and potential applications of natural cellulose fibers from corn husk. *Green Chemistry*, 7(4), 190-195.
 17. Schellenberg, J.; and Wallis, M. (2010). Dependence of properties of expandable polystyrene particle foam on degree of fusion. *Journal of Applied Polymer Science*, 115(5), 2986-2990.

18. Poletto, M.; Zeni, M.; and Zattera, A.J. (2012). Effects of wood flour addition and coupling agent content on mechanical properties of recycled polystyrene/wood flour composites. *Journal of Thermoplastic Composite Materials*, 25(7), 821-833.
19. Lye, S.W.; Aw, H.S.; and Lee, S.G. (2002). Adhesives for bead fusion of recycled expandable polystyrene. *Journal of Applied Polymer Science*, 86(2), 456-462.
20. Chaukura, N.; Gwenzi, W.; Bunhu, T.; Ruziwa, D.T.; and Pumere, I. (2016). Potential uses and value-added products derived from waste polystyrene in developing countries: a review. *Resources, Conservation and Recycling*, 107, 157-165.
21. Hu, X.; Fang, J.; Xu, F.; Dong, B.; Xiao, Y.; and Wang, L. (2016). Real internal microstructure based key mechanism analysis on the micro-damage process of short fibre-reinforced composites. *Scientific Report*, 6, 1-9.
22. Danyadi, L.; Moczo, J.; and Pukanszky, B. (2010). Effect of various surface modification of wood flour on the properties of PP/wood composites. *Composites Part A*, 41(2), 199-206.
23. Poletto, M.; Dettenborn, J.; Zeni, M.; and Zattera, A.J. (2011). Characterization of composites based on expanded polystyrene wastes and wood flour. *Waste Management*, 31(4), 779-784.
24. Chun, K.S.; and Husseinsyah, S. (2017). Comparison study on green coupling agents from different type of plants oil for agrowaste-based thermoplastic composites. *Journal of Thermoplastic Composite Materials*, 30(7), 938-949.
25. Chun, K.S.; Yeng, C.M.; and Hussiensyah, S. (2018). Green coupling agent for agro-waste based thermoplastic composite. *Polymer Composites*, 39(39), 2441-2450.
26. Joseph, K.; and Thomas, S. (1996). Effect of chemical treatment on the tensile properties of short sisal fibre-reinforced polyethylene composites. *Polymer*, 37(23), 5139-5149.
27. Penjumras, P.; Rahman, R.A.; Talib, R.A.; and Abdan, K. (2015). Mechanical properties and water absorption behaviour of durian rind cellulose reinforced poly(lactic acid) biocomposites. *International Journal of Science, Engineering and Information Technology*, 5(5), 343-349.
28. Chun, K.S.; Husseinsyah, S.; and Yeng, C.M. (2016). Green composites from kapok husk and recycled polypropylene: processing torque, tensile, thermal, and morphological properties. *Journal of Thermoplastic Composite Materials*, 29(11), 1517-1535.
29. Jiao, L.L.; and Sun, J.H. (2014). A thermal degradation study of insulation materials extruded polystyrene. *Proceeding of Engineering*, 71, 622-628.
30. Lei, Y.; Wu, Q.; Yao, F.; and Xu, Y. (2007). Preparation and properties of recycled HDPE/natural fiber composites. *Composites Part A*, 38(7), 1664-1674.
31. Jeske, H.; Schirp, A.; and Cornelius, F. (2012). Development of a thermogravimetric analysis (TGA) method for quantitative analysis of wood flour and polypropylene in wood plastic composites (WPC). *Thermochimica Acta*, 543, 165-171.