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Effects of aqueous extraction on the performance and properties of polypropylene/wood composites from *Phoenix dactylifera* and *Acacia tortilis* wood

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Abstract

Polypropylene/wood composites were prepared by melt blending technique using a twin screw extruder and subsequently ASTM samples were also prepared by injection molding technique. Untreated and pre-treated particles of *Phoenix dactylifera* and *Acacia tortilis* woods are used in this study to investigate the effect of pre-treatments on the different properties of polypropylene/wood composites. The tensile strength of the wood composites was evaluated by ASTMD-638 method and it was found to be higher than the neat polypropylene. The effect of incorporation of wood particles on the melting temperature (T_m), crystallization temperature (T_c) and relative crystallinity (X_c) was also studied and reported. The viscoelastic properties of the PP/wood composites were evaluated. The temperature sweep experiments reveals that the composites storage modulus (G') has higher values than the neat polypropylene at elevated temperature. The water uptake test showed that the composite samples have improved water repletion properties. Water uptake of untreated PP/date palm composites increased from 0.042% after 2 h to 0.12% after 120 h of immersion time. Pre-treated date palm reduced water uptake to 0.077% after 120 h of immersion time. Similar trend was also observed for the composites prepared from *A. tortilis* wood. The interaction between the wood and the polymer matrix was characterized by Fourier transform infrared spectroscopy technique. The interfacial and the distribution of the wood particles in the polymer matrix were also investigated by scanning electron microscopy.

Keywords

Polypropylene/wood, scanning electron microscopy, Fourier transform infrared spectroscopy, composite, wood particles, pre-treatment, cold water, hot water, tensile strength, storage modulus, water uptake

Introduction

Industrial development of wood/polymer composites has still many limitations, although the properties and utilizations of these products are dramatically increased in the last four decades. Beside the poor compatibility between non-polar, hydrophobic polymers and the polar, hydrophilic wood particles, low thermal stability and high moisture absorption of wood are the most important limitations.[1–5] Wood/polymer composites are manufactured by compounding wood particles with polymer matrix at a temperature above the melting temperature of the polymer (up to 200°C). The thermal degradation of wood is started at about 273°C.[6] High processing temperature may cause degradation of wood during manufacturing of WPCs which can lead to undesirable properties such as odor, discoloration and decrease in mechanical properties of WPCs.[3]

Many research papers had been reported about preparation and characterization of wood-polymer

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composites.[5,7–10] In the last two decades, much effort has been made to improve the interfacial bonding strength between the polar wood and nonpolar thermoplastic matrix.[5,11,12]

Shebani et al.[3] reported thermal stability of cellulose extracted from four different wood species and found that pre-treated cellulose exhibited higher thermal stability than the wood itself. This allows the processing of these woods with a polymer above 200°C. They found that the thermal stability of these species improved due to the extraction by hot water, ethanol/cyclohexane and their combination

Unpleasant smell can be emitted during the production of WPCs or may create negative effect on the thermal stability of the final products.[13] The influence of wood extractives on the thermal stability of wood and WPCs has not been studied extensively. Pan et al.[14] reported that the particle board made from hot water-treated wood particles showed better mechanical properties and dimensional stability than those made from untreated wood particles. The literature on using pre-treated wood particles for the preparation of WPCs are limited.

Wood contains in addition to the major cell wall components (cellulose, hemicellulose and lignin), secondary components of nonstructural, low molecular weight that are categorized as extractives. The latter are soluble in neutral, non-polar, organic solvents and cold water.[15] Generally, the total extractive content of wood (based on oven-dry weight) varies between less than 1 and 5% but can be up to 30% in extreme cases.[3,16] The amount and composition of extractives differ in the solvent used,[17] and also differ markedly in various parts of the tree and species,[18] harvesting season,[19] silvicultural practices[20] and storage time.[21]

Composites prepared from thermoplastics and wood fiber has been gaining interest. The manufacture of these composites is associated with the incompatibility of polar wood (hydrophilic) and non-polar polymer (hydrophobic) leading to difficulties in obtaining good dispersion of the wood particle and poor reinforcement of the polymer matrix by the wood.[11,12] During the past decade, there has been a rapid growth in the development and study of composite materials.[21–26] In the literature, there are several methods that can be used to overcome the problem of poor compatibility between wood fibers and thermoplastics polymers. Pre-treatments of fibers, use of coupling agent and dispersion agents were reported.[27–30] Viksne et al.[10] studied the feasibility of two wood-derived fillers (WDF) which are tetra pack cartoon cellulose fiber and birch veneer sanding dust from waste of different origins as reinforcing filler for polypropylene (PP) and compared with similar loading (40% by wt) talc-filled PP. It was found that talc composites exhibit greater flexural modulus at temperatures of less than 0°C, higher impact strength at room temperature and are easier to process than WDF composites, However, PP filled with WDF displayed higher flexural modulus at plus temperatures and tensile strength over the whole temperature range used in the study.

Dundar et al.[4] reported some physical and mechanical properties of PP composites reinforced with various mixtures of the cone flour and the wood flour. Five wood plastic composite (WPC) types were made from the mixtures of cone flour/wood flour/PP/coupling agent, respectively. Water resistance and flexural properties of the composites were negatively affected by increasing cone flour content. They concluded that the extractives in the cone flour on the mechanical properties of wood-PP composites had a significant effect on the flexural properties of the composites. Based on the findings obtained from the present study, with the addition of 10% cone flour to WPC, the water resistance and flexural properties were not significantly affected as compared to WPC made from wood flour.

Doroudiani and Kortschot[31] studied about processing–structure–mechanical properties relationships in expanded wood fiber polystyrene composites (EPSC) made with a physical blowing agent. The objective of the current study was to investigate the effects of wood extractives on the properties of wood/polymer composites including thermal and dimensional stability. WPCs filled with extracted and un-extracted four wood species and date palm midrib fronds were tested to study the effect of pre-treatment of wood particles on the properties of wood/polymer composite panels.

Table 1. Physical properties of PP

Physical properties[a]	Value	ASTM method
Melt index, g per 10 min	25.0	D-1238
Density, g cm^{-3}	0.954	D-1505
Vicat softening point, °C	153	D-1525
Tensile strength@yield, MPa	36	D-638
Hardness, shore D	104R	D-2240

PP: polypropylene.
[a]Reported by supplier.

Table 2. Melt blending conditions of twin screw extruder

Barrel temperature (°C)		Screw speed (rpm)	Melt pressure (bar)
Zone 1	Zone 2–6		
230	230	15	12

Table 3. Injection molding conditions of the ASTM nanocomposites sample

Screw speed (rpm)	Temperature (°C)				Injection pressure (bar)	Cooling time (sec)	Cycle time (sec)
	T_1	T_2	T_3	Feed zone			
200	210	230	230	170	500	30	35

Materials and methods

PP homopolymer from the local market (SABIC) was used in this work. It is an injection molding grade of PP homopolymer with a narrow molecular weight distribution and high flowability. A list of some of its properties is shown in Table 1 as provided by the supplier.

Particles preparation

The lignocellulosic materials used for the current study were pruning residues of date palm (*Phoenix dactelifera* L.), which are midribs of fronds collected from the seasonal pruning process in 2010 of date palm trees and *Acacia tortilis*. These woody materials were collected from different locations in the Kingdom (Riyadh, Al-Dammam, and Southwest of the Kingdom) to produce WPCs. Theses materials were air-dried and then reduced to smaller pieces in order to facilitate grinding into meal. These smaller wood pieces were feed into a crusher (Model R25; CR Clarke, UK). Wood meal passing through a 0.40-mm sieve (40-mesh screen) and retained on a 0.27-mm sieve (60-mesh screen) was used for chemical analysis, while those meals that pass through a 0.27-mm sieve (60-mesh screen) and retained on a 0.20-mm sieve (80-mesh screen) were used to prepare WPC formulations.

Pretreatments of the wood particles

Two kinds of pretreatments were done in order to enhance the performance of wood/PP composites. These are hot and cold water extraction. For hot water extraction, a portion of lignocellulosic particles (date palm or acacia tortilis) were extracted by hot water extraction for 6 h with changing the water every 2 h according to the method outlined by Moslemi et al.[32]

Cold and hot water treatments

About 500 g of oven-dried wood meal (40-60 mesh) were soaked in cold distilled water or extracted in boiling distilled water for 48 h or 3 h, respectively, according to Moslemi and Lim[33] with some minor modification. The pH of the extracts was measured with a pH meter. To avoid the formation of undesirable foams that arise from wood moisture, the lignocellulosic particles were dried at oven temperature of 100°C or 80°C for about 18 h in order to remove moisture according to the material types to avoid discoloration that may result from charring of extractive materials.

Chemical analysis of the wood lignocellulosic materials

For each lignocellulosic material, chemical components were determined according to the standard methods. These include extractive content,[34] cellulose content,[35] hemicellulose content,[36] solubilities in cold and hot water,[37] and ash content.[38]

Specific gravity determination

A disc was cut from each tree at breast height and from date palm midrib fronds, thereafter, small specimens were cut from each disk with about dimensions of 2 cm × 2 cm × 2 cm. Specific gravity was then evaluated according to the maximum moisture content method outlined by Smith.[39]

Compounding

PP was dry-blended with wood particles at 10/90 wood/PP ratio by weight. The dry-blend was pelletized using an intermeshing and co-rotating twin screw extruder, Farrell FTX20. The screw diameter was 26 mm and the length to diameter ratio was 35. The screw had both dispersive and distributive mixing elements. The dry-blends were fed to the extruder which was operating at a screw speed of 12 rpm and at average processing temperature of 235°C. The melt pressure was about 7 bar. The extrudate was cooled in a water bath, dried and pelletized for further use. The details of the compounding conditions are listed in Tables 2 and 3. One control material with six other PP/wood composites were prepared as listed in Table 4.

Injection molding

An injection molding machine (Asian Plastic Machinery Co., Double Toggle IM Machine, Super Master Series SM 120) was used to mold samples for further characterization. The molding conditions are listed in Table 3. The molded specimens were conditioned at 23°C for 24 h before testing.

Table 4. A list of the samples prepared for this work

Species	Pretreatment	Code	Description
Date palm	Untreated	DP-UN	Untreated date palm frond particles
	Cold water	DP-CW	Date palm frond particles pre-treated with cold water
	Hot water	DP-HW	Date palm frond particles pre-treated with hot water
Acacia tortilis	Untreated	AT-UN	Untreated *Acacia tortilis* wood particles
	Cold water	AT-CW	*Acacia tortilis* wood particles pre-treated with cold water
	Hot water	AT-HW	*Acacia tortilis* wood particles pre-treated with hot water
PP	—	Control	PP homopolymer

PP: polypropylene.

Tensile test

The tensile response of the dumbbell-shaped specimens (ASTM D638) of all the composite samples were studied at room temperature, using a Hounsfield H100 KS series tensile testing machine. The samples were conditioned prior to testing at room temperature for 24 h. The tensile tests were performed at a cross-head speed of 100 mm/min. The reported measurements for all the above tests represent the median of three experiments.

Morphological analysis

The SEM was used to observe the surface morphology of the as-molded specimens as well as the cryo-fractured samples. The cryo-fractured samples were prepared by soaking molded samples that contain a controlled crack in liquid nitrogen for more than 5 min, then quickly fracture them using impact force to avoid material deformation. The surfaces of the samples were coated with gold under vacuum prior to the SEM observation to avoid electrostatic charging during examination.

Differential scanning calorimetry

Differential scanning calorimetry (DSC) Shimadzu DSC-60 was used for this analysis. Specimens of about 6–7 mg each were prepared out of the compounded pellets. Each specimen was prepared by "shaving-off" a thin layer, less than 1 mm thickness, of the pellets to minimize the thickness effect. Each specimen was put in an aluminum pan without being sealed, then placed in the DSC oven in air at atmospheric pressure. Samples were heated at 5°C/min from room temperature to 200°C, held at this temperature for 10 min and then cooled back to room temperature at a cooling rate of 5°C/min. The melting temperature (T_m) and the crystallization temperature (T_c) of PP were taken at the peaks of the melting and crystallization processes, respectively. The onset crystallization temperature (T_{oc}) was determined at the beginning of the crystallization (at the intersection of the peak slope with the baseline). The melting and crystallization enthalpies, (ΔH_m) and (ΔH_c), were determined from the corresponding peak areas in the heating and cooling DSC scans, respectively. For each sample, DSC measurements were repeated three times. The DSC machine was calibrated with Indium proper to the measurements and the machine error was $\pm 0.5°C$.

Viscoelastic properties

The viscoelastic properties of the samples were characterized with AR G2 Rheometer made by TA. The linear viscoelastic storage and loss moduli were measured in torsion mode at 80°C, the limits for the rotation angular frequency varying between 0.1 and 100 rad/s. The specimen for this analysis was taken from injection molded samples cut into rectangular stripes of $28 \times 3.20 \times 13.4\ mm^3$ to fit the rheometer's fixtures. The temperature was stable within 0.2°C over the range used in this study. The torsion moduli reported in the following are those measured in the linear viscoelastic response region. All tests were performed in air atmosphere.

For the dynamic linear viscoelasticity of the melt, the samples were compression-molded at 190°C under a pressure with required diameter disks to fit the rheometer fixtures. The linear viscoelastic functions were measured using the parallel plate geometry (diameter = 25 mm and gap = 1000 micron). Frequency scans were performed in the range between 0.1 and 100 rad/s at 190°C. Strain sweeps were previously performed to investigate the linear viscoelastic response region, and time sweeps were also performed to test the melt stability of the samples. All of the reported measurements for all of the experiments are the representation of three different experiments.

Table 5. Chemical analysis of the two woody materials

Chemical constituent (%)	Species	
	Phoenix dactelifera	Acacia tortilis
Total extractives	21.43a	8.05b
Cellulose	46.57b	47.69a
Hemicelllulose	24.86a	21.20b
Lignin	26.17b	29.43a
Ash	5.32a	2.86b
Cold water solubility	15.28a	4.94b
Hot water solubility	21.65a	6.78b

Note: Means with the same letters in row are not significantly differences at 5% level of probability according to LSD test.

Table 6. Specific gravity, density and moisture content of the two wood species used

Lignocellulosic materials	SG_{Diana}	Density (g cm^{-3})	Moisture content (%)
Acacia tortilis Sapwood	0.705	0.703	14.038
Acacia tortilis Heartwood	0.703	0.691	11.296
Phoenixdactylifera	0.141	0.138	37.134

Note: Each value is an average of five specimens.

FT-IR

Fourier transform infrared spectroscopy (FTIR) of the samples was recorded by attenuated total reflectance (ATR) technique using a Thermo Scientific iZ10 FT-IR machine.

Results and discussions

Chemical analysis

Table 5 describes the chemical analysis results of the two wood species. It is observed that both the species has almost same level of lignin whereas the ash content of *Acacia tortilis* is lower than the *Phoenix dactelifera*. The cold/hot water solubility of *Phoenix dactelifera* is higher than the *Acacia tortilis*.

The specific gravity of *P. dactylifera* was found to be lower than *A. tortilis*. The values of the specific gravity are show in Table 6.

Mechanical properties of the wood/PP composites

The tensile strength of wood/PP composites made of treated and untreated wood particles from date palm fronds and *A. tortilis* are presented in Figure 1. These data demonstrate that tensile strength increases with the incorporation of the wood in the PP matrix. Pretreated *Acacia tortilis* wood particles by hot water (AT-HW) showed the highest increment in tensile strength (29.8 MPa) among different combination compared with neat PP (19.9 MPa) or untreated wood (25.4 MPa). This clearly demonstrated the reinforcing effect of the wood in PP matrix. It was also observed that the hot water extraction increases the strength most which may be attributed to the increased compatibility of the PP matrix with the treated wood particles. No significant differences were found between cold and hot water extraction of either date palm fronds or *A. Tortilis*. It can be concluded that the pretreatement of the two wood species used in the present study significantly affected the tensile properties composiots.

This improvement may be attributed to the removal of sugars and other water-soluble extractives from wood, which appear to be highly hydrophilic substances.[30] The removal of these substances may improve the compatibility between wood and polymer matrix.[40] These results are in agreement with the results of research carried out in other parts of the world,[22,29,41–43] Mansour et al.[22] reported that the treatments of the wood plant or the use of chemithermo mechanical pulp is very important to obtain composites with low void contents and high bending strength. Nasser[30] concluded that extraction of wood by either hot water or 4% NaOH improved the mechanical and physical properties of wood-plastic composite panels made of cotton stalks, casuarinas and European redwood with low-density polyethylene.

Viscoelastic properties of PP/wood composites: melt state

A plot of the complex viscosity (η^*) versus the angular frequency for the PP/wood composite samples at 190°C are shown in Figures 2 and 3. Compared to neat PP, η^* of PP/date palm pre-treated with cold water (DP-CW) and PP/Acacia wood pretreated with hot water (AT-HW) was higher which may be due to the presence of wood particles and to pre-treat the wood by aqueous solution. The wood particles would have disturbed the normal flow of polymer and increased its viscosity.[44] This phenomenon is usually observed in dilute suspensions of rigid particles. However, the viscosity in the sample other composites showed the reverse trend. This may be due to the diluting affect of the wood particles to the PP matrix or removing the soluble materials from wood by using pre-treatment. However, the viscosity in the other composite including PP/untreated wood showed the reverse trend.

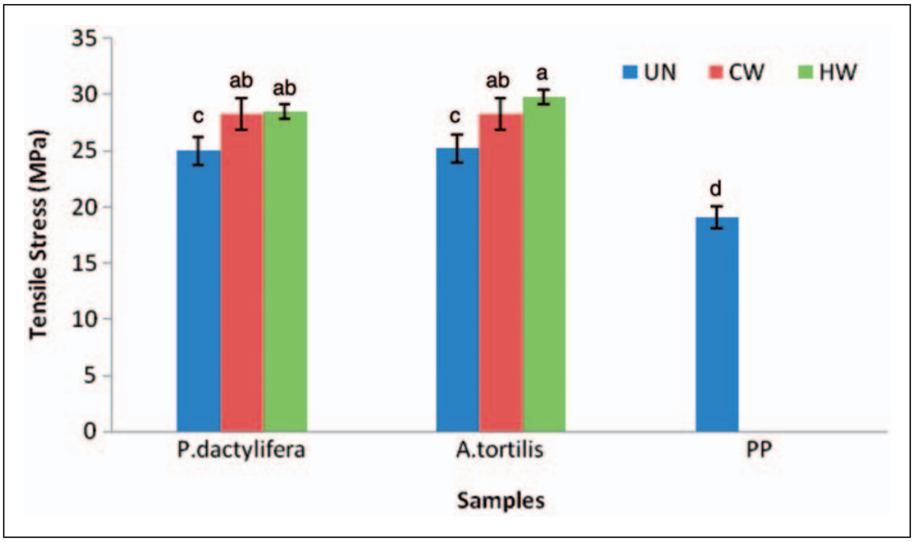

Figure 1. Effect of pretreatments on tensile strength of wood/polypropylene (PP) composites.
Generally and statistically view; researchers put either standard deviations (line on the top of bars) or LSD.

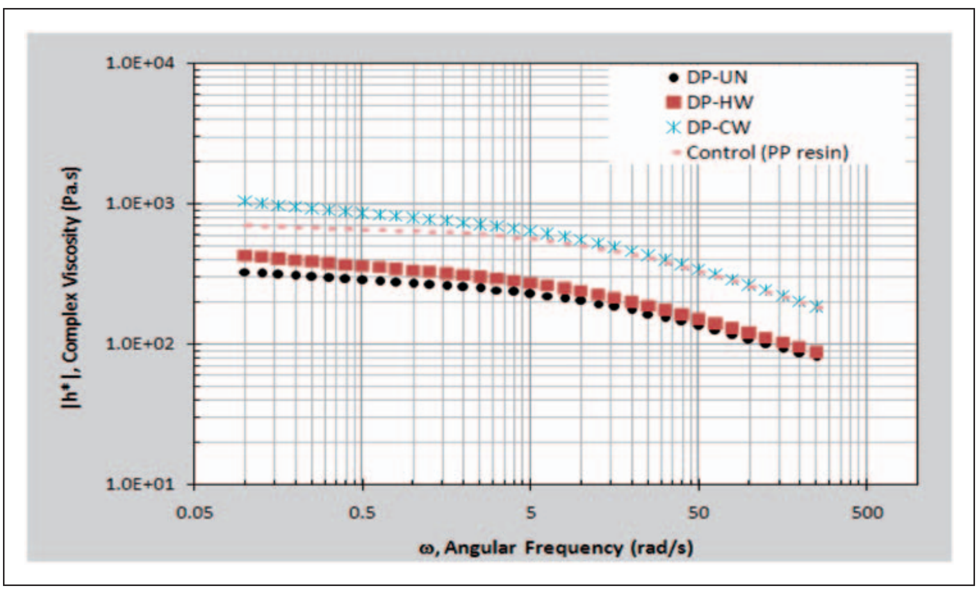

Figure 2. Complex viscosity (η^*) curves of polypropylene (PP)/date palm wood composite at 190°C compared to neat PP.

Viscoelastic properties of PP/wood composites: solid state

The storage moduli (G') of neat PP and PP/wood composites at 80°C are plotted against the radial frequency in Figures 4 and 5. Compared to neat PP, the storage moduli of PP/wood composite samples increased, especially at low frequency. It can be seen that pre-treating of particles increased the storage modulus. These results suggest that PP/wood composite could have higher creep moduli than neat PP, however, the moduli of all materials under impact would be the same. The storage modulus enhancement could be attributed to stiffness imparted by wood particles (R), which will increase the overall stiffness of the composites as compared to the neat resin (PP).

Thermal properties of PP/wood composites

DSC analysis. Figure 6 depicts the dynamic temperature thermograms of neat PP and PP/wood composite samples. The thermograms were shifted vertically for ease of presentation. The endothermic melting peaks for all

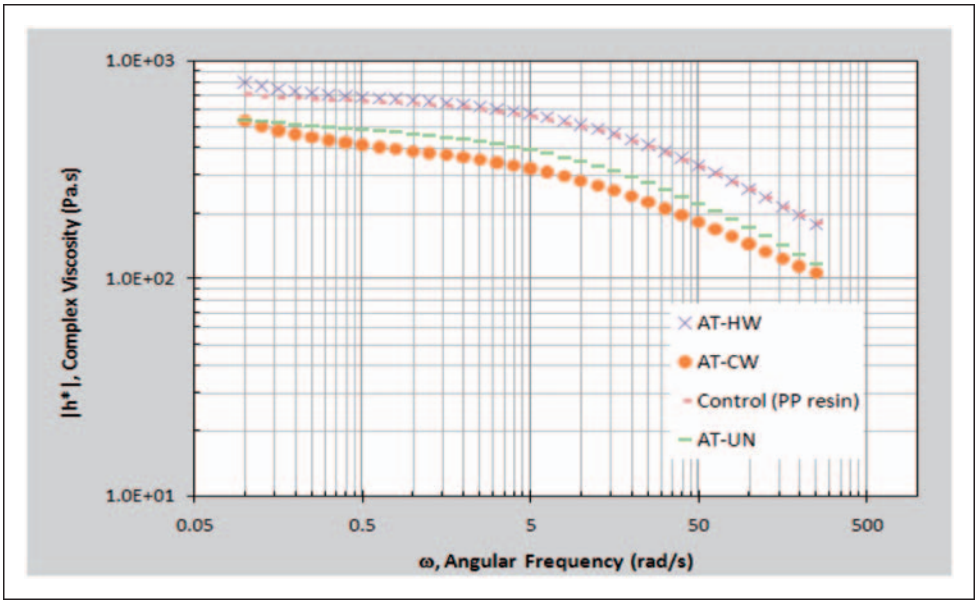

Figure 3. Complex viscosity (η*) curves of polypropylene (PP)/*Acacia tortilis* wood composite at 190°C compared to neat PP.

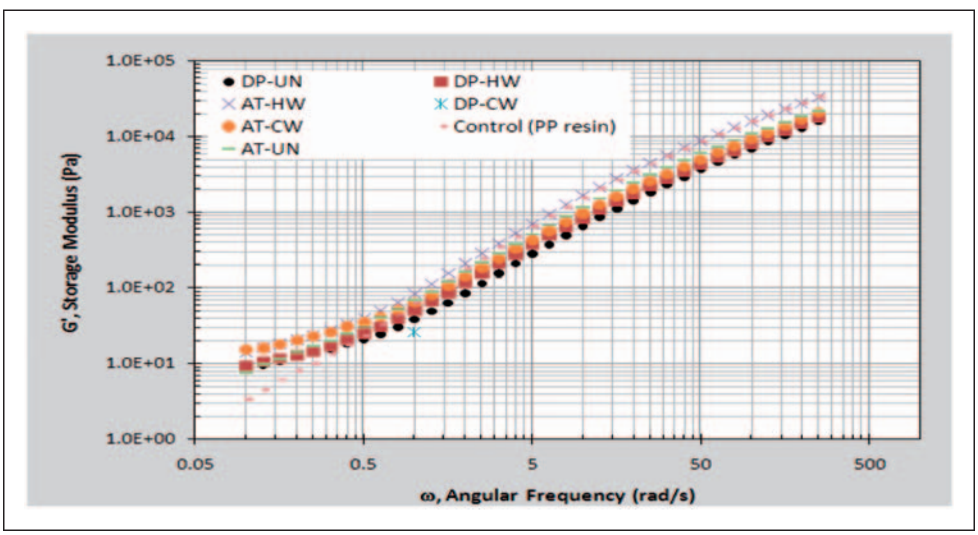

Figure 4. Dynamic modulus curve of polypropylene (PP)/wood composites at 80°C.

materials looked similar, however, two differences in the melting behavior between neat PP and PP/wood composite samples could be observed. Firstly, the melting temperature (T_m) increased for PP/wood composite samples as illustrated in Table 7. Higher melting temperatures are indicative of thicker lamella as indicated by the Thompson-Gibbs equation. Such thickness-melting dependence of PP crystallites is well documented in literature.[45] Comparing the stability of PP and PP/wood composites indicates that the presence of lignocellulosic fibers (date palm) imparts stability to the composite material.[46] They explained this result by the presence of natural antioxidants, for example lignin, which is known to stabilize the natural fibers.

Figure 7 shows the cooling thermograms of neat PP and PP/wood composite samples. The shapes of the exothermic crystallization peak of all the samples were comparable to each other. However, some differences were observed as seen from Table 7. The crystallization temperature (T_c) has increased for the composite samples as compared to the neat PP, this may be attributed to the heterogeneous nucleating effect of PP by the wood particles. For the relative crystallinity measurements, the samples were heated with a

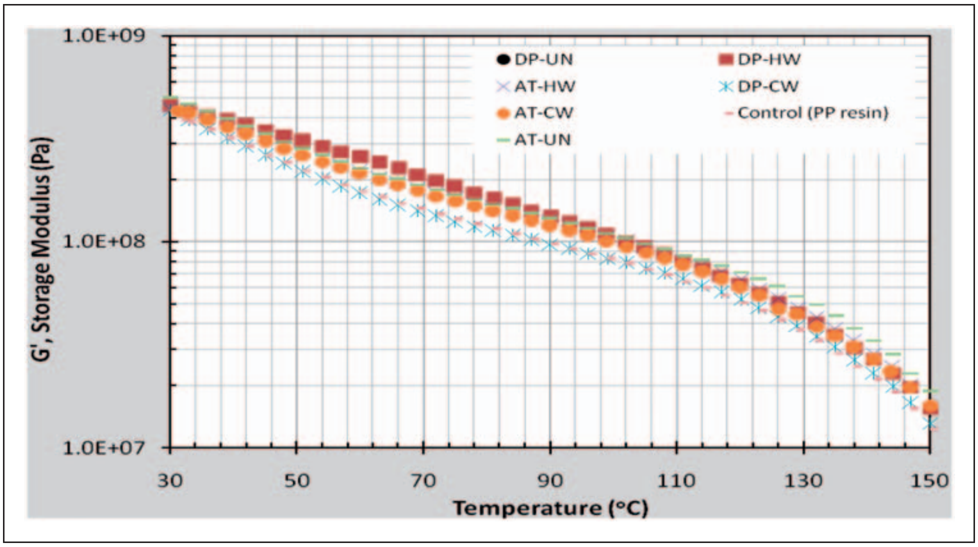

Figure 5. Dynamic modulus curve of polypropylene (PP)/wood composites as a function of temperature.

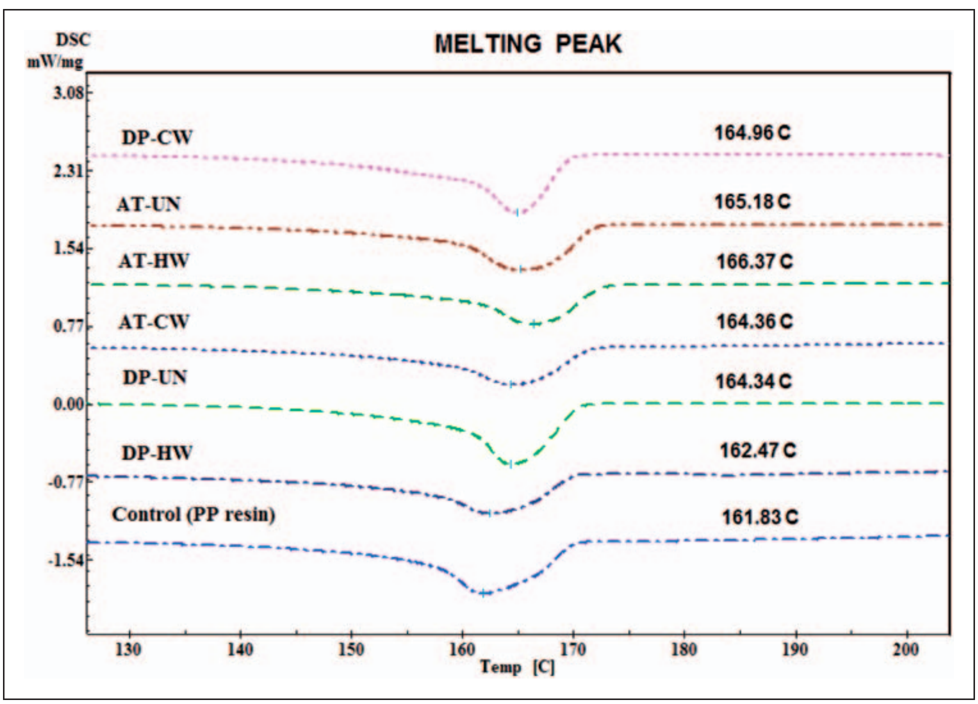

Figure 6. Differential scanning calorimetry (DSC) of polypropylene (PP)/wood composites in heating and cooling scans.

constant heating rate of 10°C/min from ambient temperature up to 200°C (approx. 30°C higher than the melting point of PP) in air environment. They were held for 5 min at 200°C to erase their thermal history and to permit the complete melting of the crystals. Subsequently, samples were cooled down to 30°C at a cooling rate of 10°C/min to study the crystallization process. Finally, they were heated again for the second time (2nd heating scan) at a rate of 10°C/min up to 350°C to melt the crystals formed at the crystallization temperature and to find the melting temperature of each nanocomposite samples. The corresponding thermogram was recorded. All curves were normalized to the unit weight of the sample.

The melting temperature, T_m, was taken as the maximum temperature of the transition endotherm curve from the 2nd heating scan, whereas, the crystallization temperature, T_c, was taken as the maximum temperature of the transition exothermic curve. The crystallinity of the specimen could be calculated

Table 7. Thermal properties of PP/wood composites made from date palm fronds and *Acacia tortilis*

Species	Pretreatment	Code	T_c (°C)	T_m (°C)	T_d (°C)	ΔH_m (J/g)	X_c (°C)
P. datylifera	Untreated	DP-UN	124	164.43	230.73	61.76	29.84
	CWE	DP-CW	125.81	165.04	230.25	49.15	23.74
	HWE	DP-HW	121.01	162.56	244.98	49.01	23.68
A. tortilis	Untreated	AT-UN	121.99	165.35	224.87	49.98	24.14
	CWE	AT-CW	121.08	164.54	207.06	45.85	22.15
	HWE	AT-HW	122.36	166.47	218.81	42.6	20.58
Neat PP			119.3	161.91	229.92	60.87	29.41

PP: polypropylene; T_c: temperature of crystallization; T_m: temperature of melting; $\Delta H_m/\Delta H_c$: enthalpy.
Note: CWE and HWE are cold water soaking and hot water extraction, respectively.

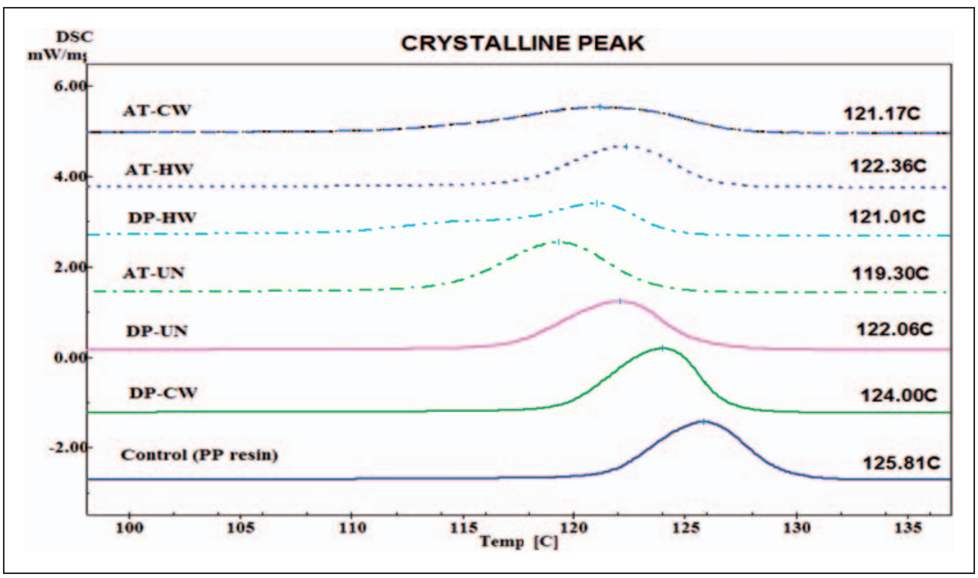

Figure 7. Differential scanning calorimetry (DSC) of polypropylene (PP)/wood composites in heating and cooling scans.

from the experimental heat of fusion ΔH_m and the literature value of 100% crystalline polymer material. Literature indicates that ΔH_m^o for PP is 207 J/g. The following equation was used to estimate the percentage of crystallinity (X_c):

$$X_c = \frac{\Delta H_m}{\Delta H_m^o} \cdot 100[\%] \quad (1)$$

FTIR of wood/pp composites

The FTIR spectrum of the PP/wood composite samples was recorded in ATR mode and the FTIR spectrum are shown in Figure 8. The FTIR spectra of both the wood species showed the presence of typical peaks at 3400 cm^{-1} for –OH functional group which is attributed to the cellulose present in the wood. Other peaks at 2900 cm^{-1} (CH stretching), 1740 cm^{-1} (CO stretching), 1636 cm^{-1} (OH bending) and below 1000 cm^{-1} (out of plane CH bending vibration) were also observed for both the wood species.

All the composite samples showed a similar FTIR spectrum. The presence of the wood is clearly visible in these spectrums. As the wood % is not high, FTIR spectrum of the composite did not show all the peals related to wood. As PP resin does not have any additional functionality to react with the –OH group of cellulose of the wood particles, we did nor observe any changes in the PP resin (Devi et al., 2012).[40]

Morphological analysis

The morphological investigation of the cryo-fracture samples showed a good dispersion of the wood particles in the PP matrix for all of the samples. However, voids are observed around the wood particles, which indicate

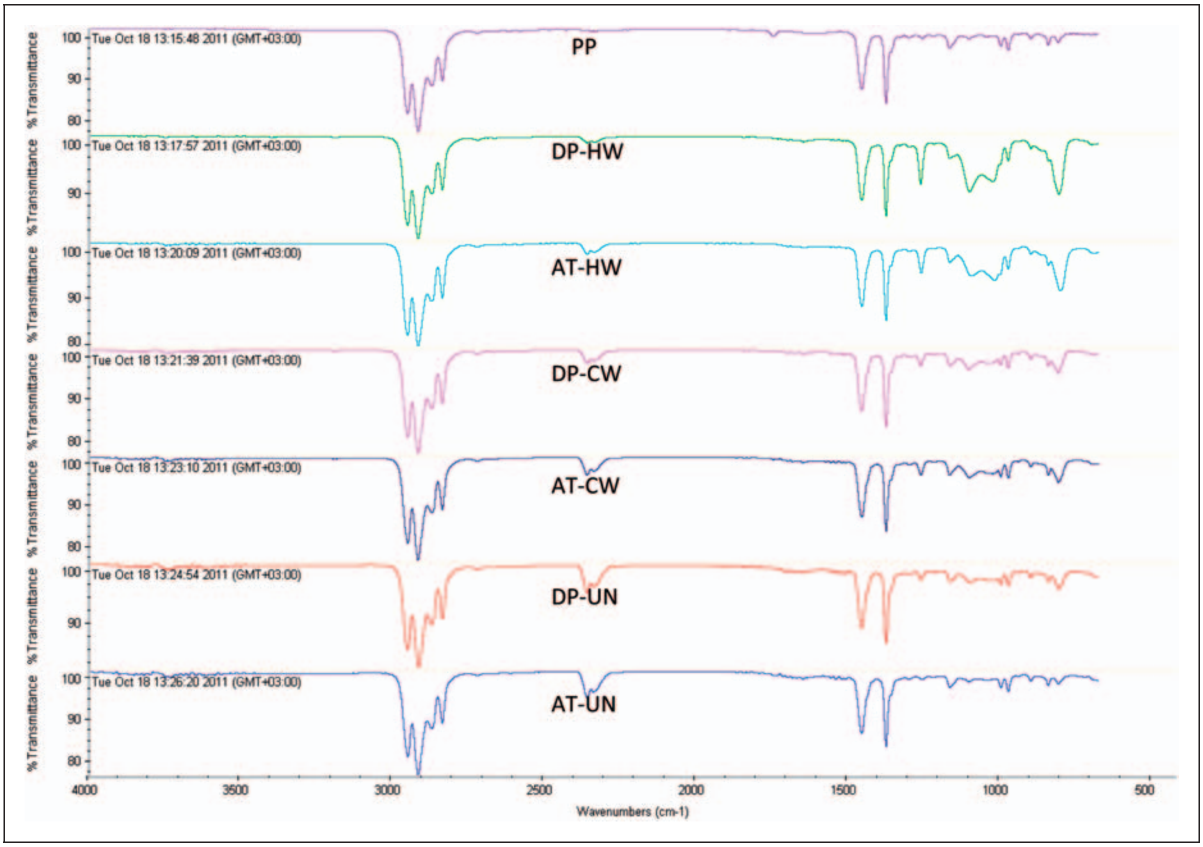

Figure 8. FT-IR spectrum of the polypropylene (PP)/wood composite samples and neat PP.

the low level of adhesion between the wood and the polymer matrix. During tensile tests in filled wood composites, a stress-whitening zone develops throughout the length of the neck, which can be attributed to the various processes that can take place in the polymer, such as matrix crazing, matrix shear yielding and filler/matrix debonding. In our this study, we also observed similar stress whitening, which is primarily due to the debonding of wood particles from PP matrix. The fractured micrograph (10) of the PP and PP/wood composites displays an interplay of multiple voiding and matrix fibrillation. The SEM investigation of the composite samples showed that the composites break through fibrillation of the PP matrix. At higher magnification, the debonded wood particles can be clearly observed from the matrix. From the SEM observation, it is found that the pre-treatment enhances the interfacial adhesion between the wood particles and the PP polymer matrix as compared to wood particles without any treatments, which can be attributed to the higher mechanical strength of the composites (Figure 9).

Water uptake of PP/wood composites

All the samples were dried and the dimensions and the weights were measured. The samples were then immersed in distilled water at room temperature (23°C) and weights were taken after 1, 6, 24, 48, 96 and 120 h, respectively, and expressed as a percentage using the following equation:

$$\text{Water uptake }(\%) = [(W_t - W_d/W_d)] \times 100$$

where W_d is the oven dry weight; and W_t is the weight after immersion in distilled water for a specified time period.

It can be seen from the Figure 10 that water uptake of the composites made with each of the two wood species decreased by using pretreatments (cold and hot water). Generally, most PP/wood composites in this study had lower water absorption after 120 h. It is clearly demonstrated that the composite made from date palm treated by hot water (DP-HW) and date

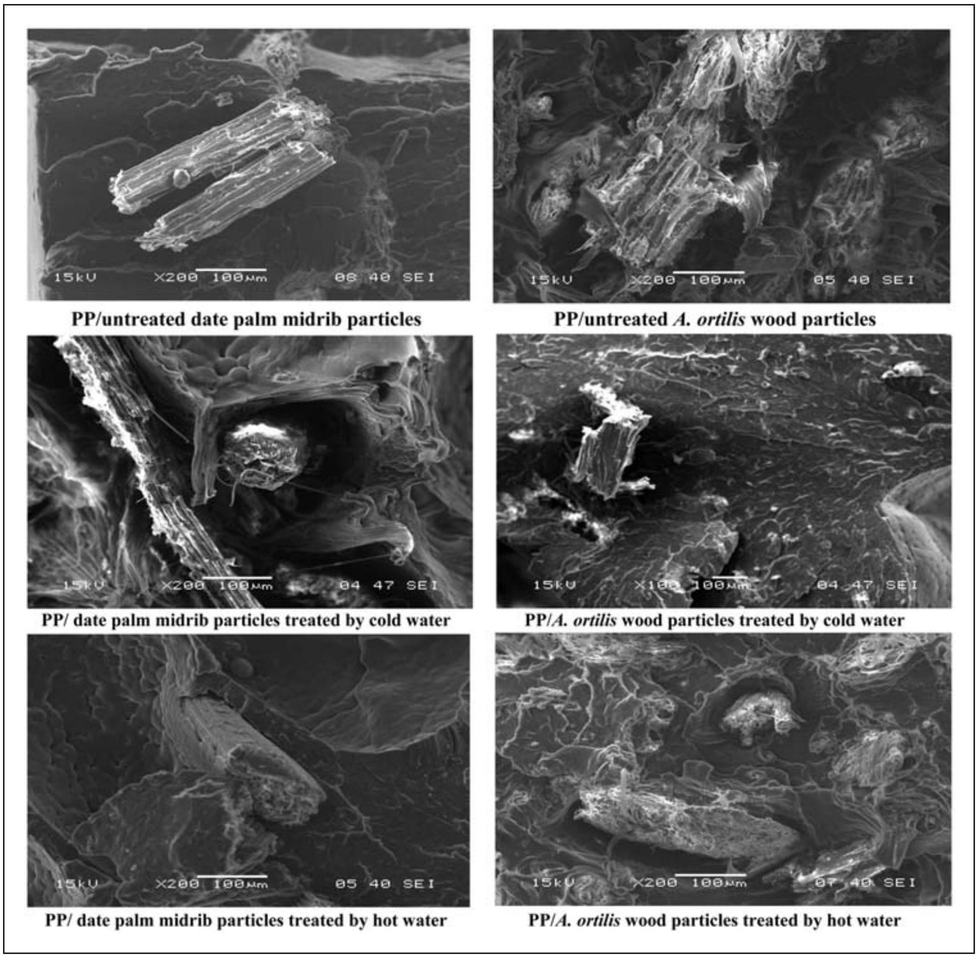

Figure 9. Scanning electron microscopy (SEM) micrographs of tensile fractures samples of the wood/polypropylene (PP) composites showing the effect of pre-treating of particles.

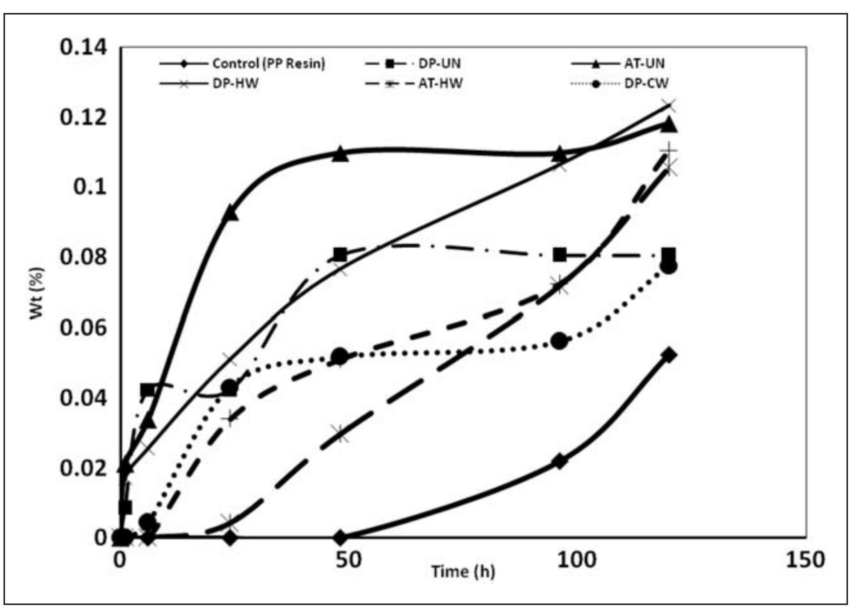

Figure 10. Water uptake of the polypropylene (PP)/wood composites.

palm treated by cold water (DP-CW) has the lowest water absorption as compared to untreated date palm (DP-UN) and other composite samples. The same trend was obtained with the composites made from *A. tortilis* wood. These results indicated that pretreatment pretreating of the woody particles especially date palm fronds had a significant effect on the dimensional stability of the produced composites. Accordingly, these pretreatments can be used to enhance the stability of wood/PP composites toward the water absorption. A strong fiber/matrix interfacial adhesion can help to avoid the water penetration reducing the hygroscopicity, and consequently, the worsening in the mechanical performances of materials.[27] This result confirmed with Shebani et al.[3] and in agreement with Mansour et al.,[22] Guifiez et al.[30] and Adhikary et al.[41] Mansour et al.[22] reported that the palm leaves treated with water at 170°C for 1 h possess the lower water uptake, and, hence, the lower void contents. The decrease in water uptake of pretreated wood/PP composites in this work may be attributed to the enhanced interfacial adhesion between fiber and matrix, which can help to avoid the water penetration and reducing the hygroscopicity.[27,42,43]

Conclusion

The supplied 16 wood polymer composites sample was analyzed and the results are reported here. The important observations are as follows

a. Woody materials pretreated by either cold or hot water to produce wood/PP composites resulted in improvement in strand color, decrease in smoke and excessive odor during compounding process of the materials.
b. The processing of this PP/wood polymer can be done by using a regular twin screw extruder and injection molding machine.
c. The tensile strength of the PP/wood composites samples is higher than the neat PP due to the reinforcing affect of the wood particles. The pre-treatment has a positive effect on the mechanical properties of these composite samples.
d. The heterogeneous nucleating effect of the wood particles on the PP matrix is clearly observed. The relative crystallinity of the composite samples was found to be lesser than the neat PP matrix.
e. The viscoelastic properties of the composite samples were investigated and the effect of wood particles on complex viscosity, storage modulus and loss modulus is reported. The wood particles disturb the movement of the polymer chain and increase its melt viscosity.
f. The water absorption property of these composites were also evaluated and found to be better.
g. The interaction between PP matrix and wood particles are clearly observed from the FTIR analysis of these samples.
h. Morphological analysis by SEM showed the interaction of the wood with the polymer matrix in some of the PP/wood composite samples.
i. Pre-treating of wood particles of date palm fronds or *A. tortilis* had a significant effect on the properties of wood/PP composites.
j. It can be concluded that treating of particles before being compounded with PP enhances the performance of the composites, especially for date palm fronds.
k. Pre-treating date palm fronds with cold and hot water reduced water uptake to 0.077% after 120 h immersion time.

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