Article

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Water sorption and mechanical performance of preheated wood/thermoplastic composites

Alireza Kaboorani[1] **and Karl R. Englund**[2]

Abstract

Wood samples heat treated at 175°C, 190°C, and 205°C with different amounts of high density polyethylene and coupling agent were used for the production of wood/plastic composites. Measuring water sorption, thickness swelling, and diffusion coefficients of composites for a 40-week period immersion in water showed that composites with wood treatment at 190°C and 205°C had considerably higher water resistance. Adding a coupling agent reduced water sorption, thickness swelling, and diffusion coefficients, more pronounced in composites with untreated wood. Measurements of flexural properties in a control state and after 4 and 12 weeks immersion periods in water proved that heat treatment is an effective way to ease detrimental effects of water on mechanical properties. Modulus of elasticity showed more sensitivity to water exposure than modulus of rupture. Strain at maximum load increased after water exposure. Treating wood at 190°C resulted in good flexural properties and excellent water resistance.

Keywords

wood/thermoplastic composites, preheat treatment, water sorption, thickness swelling, diffusion coefficient, flexural properties

Introduction

Natural fibers have many advantages over inorganic fillers such as low cost, low density, renewable nature, high specific strength, and modulus (strength or elastic modulus per mass density of a material). Despite having these advantages, natural fibers are hydrophilic because of their cellulose and hemicelluloses constituents that make up much of the fiber composition. The hydrophilic behavior can ultimately cause weak interfacial adhesion between the fiber and hydrophobic polymeric matrix from the sorption and desorption of moisture within the composite.[1] Moisture sorption can also lead to biological attack and decay. Morris and Cooper[2] published the first report addressing fungal growth on wood/plastic composites (WPCs) in 1998. Fungal fruiting bodies were found growing on commercially manufactured composites used on boardwalk in Florida. The revelation diminished the reputation of WPCs as durable materials. It has been shown that water sorption could have detrimental effects on mechanical properties of WPCs.[3–15] Although the past research displayed the negative impact of water exposure on mechanical properties of WPCs, the issue has not been addressed fully. Moreover, the effects of water exposure duration have not been investigated and more importantly no solution has been found to minimize the mechanical loss due to immersion in water.

Heat treatment of wood prior to blending with the polymer can potentially be used as a way to reduce the water sorption of WPCs. Researchers have shown that heat treated wood is less hydrophilic.[16–23] Several reasons have been mentioned for improvement on

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[1] Département des sciences du bois et de la forêt, Université Laval, Québec, QC, G1V 0A6, Canada.
[2] Composite Materials and Engineering Center, Washington State University, Pullman, WA 99164-1806, USA.

Corresponding author:
Alireza Kaboorani, Département des sciences du bois et de la forêt, Université Laval, Québec, QC, G1V 0A6, Canada
Email: alireza.kaboorani.1@ulaval.ca

dimensional stability of heat treated wood including; loss of constitutional water in wood [20] and enhancement of cross-linking reactions of formaldehyde generated during the decomposition of wood organic acids and the phenol units of lignin.[22] Improvements in dimensional stability of wood by heat treatment can potentially provide WPCs with higher stability towards water. To our best knowledge, no research has examined the potential usage of heat-treated wood in WPCs. For the first time, this study is aimed at evaluating the effects of heat treatment of wood on water resistance of WPCs.

The hypothesis of this article is that using heat-treated wood as filler in WPCs can reduce water sorption and subsequently improve the water resistance of WPCs. The main objective of this study is to develop durable WPCs through heat treatment of wood before blending with the polymer. The effects of heat treatment temperature and coupling agent content on water resistance of WPCs as a function of time of water exposure are examined as well.

Materials and methods

The thermoplastic polymer high density polyethylene (HDPE), Petrothene® LB 0100-00 with melting flow index of 0.50 g/10 min (measured according to ASTM D 1238) and density of 0.953 g/cc was supplied by Lyondell chemical company, Houston, TX, USA. Wood flour (40 mesh maple flour) was purchased from P.W.I. Industries Inc., St-Hyacinthe, Québec, Canada. Coupling agent maleic anhydride polypropylene (MAPP) copolymer, A-C® 950P was supplied by Honeywell Company, Morristown, New Jersey, USA. Viscosity at 190°C, saponification number and density of MAPP were 1000–3000 cps, 35–50 mg KOH/g and 0.93 g/cc, respectively.

Prior to heat treatment, wood flour was dried at 100°C for 24 h. After cooling in a desicator, wood flour was heat treated for 45 min at different temperatures (175°C, 190°C, and 205°C) in an air circulated oven. Composites were produced with variable coupling agent contents. Compositions of wood/HDPE composites of this study are shown in Table 1.

Wood, coupling agent, and HDPE were mixed in an extruder. A twin-screw extruder, Leistritz ZSE18HP-400 (Somerville, NJ, USA) with a ratio of length to diameter of screw (L/D) of 40 (diameter: 18 mm) and a temperature profile of 160°C, 170°C, 180°C, 180°C, and 180°C was used to blend the materials. After palletizing extruded strands, the materials were extruded through an injection-mold to produce the composite samples. Injection molding was performed by a Sumitomo SE 50D (Norcross, GA, USA) with diameter of 25 mm and a temperature profile of 160°C, 170°C, 180°C, and 180°C.

Water sorption measurement

The water sorption measurements were conducted according to ASTM D 570. The only difference from the standard was the dimensions of samples. The dimensions of samples were: 52 mm long × 12.48 mm wide × 3.2 mm thick. The temperature of water was maintained at 23°C during the water sorption test. Before immersion in water, the samples were dried at 50°C for 24 h. The weight of samples after being dried for 24 h (W_o) was used as a base to calculate water sorption at a given time (H_t). The water sorption measurements were conducted for 40 weeks. The water sorption was calculated using the following equation:

$$H_t = \frac{W_t - W_o}{W_o} \times 100 \tag{1}$$

where H_t is the water sorption after spending given time in water; W_t, weight of samples after spending

Table 1. Compositions of wood/HDPE composites

Formulation number	Code	HDPE (%)	MAPP (%)	Wood (%)	Heat treatment temperature (°C)
1	0C/0T	50	0	50	–
2	2C/0T	48	2	50	–
3	0C/175T	50	0	50	175
4	2C/175T	48	2	50	175
5	0C/190T	50	0	50	190
6	2C/190T	48	2	50	190
7	0C/205T	50	0	50	205
8	2C/205T	48	2	50	205

C, coupling agent content; *T*, heat treatment temperature.

given time in water; and W_o, weight of samples after being dried for 24 h

Thickness swelling

The thickness swelling of samples was measured after immersion in water for 40 weeks. The sizes of samples used for thickness swelling tests were the same as water sorption tests. Thickness was measured in three points on each sample.

Diffusion coefficients

Different models have been developed to describe the moisture sorption of materials.[6] As shown by other researchers,[5,7,9,24] the process of water sorption by wood/thermoplastic composites follows kinetics and mechanisms described by Fick's law. The characteristics of Fick's laws of diffusion can be described as: (1) the sorption curves are linear in the initial stages, and (2) above the linear portion both sorption and desorption curves are concaves to abscissa.

The moisture content, M_t for a period of time as a function of square root of time for a typical Fickian process schematically is given in Figure 1. The relative rates of moisture sorption for three-dimensional materials were considered by comparing their respective diffusion constants. For a thin (thickness<<width) and long (thickness<<<length) specimen, diffusion is considered to be one-dimensional.

The apparent one-dimensional diffusion coefficient (D_A) can be calculated according to Fick's law by using the following relation established by Springer:[25]

$$D_A = \pi\left[\frac{h}{4M_m}\right]^2\left[\frac{\mathrm{d}M_t}{\mathrm{d}\sqrt{t}}\right]^2 \tag{2}$$

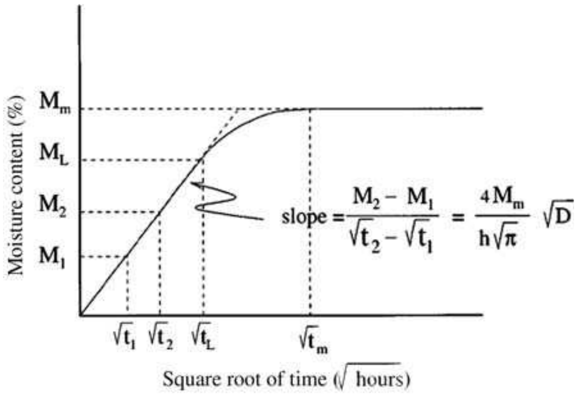

Figure 1. Moisture content as a function of time for a typical Fickian process.[25]

where M_m is the weight gain percentage at saturation point, D_A the apparent diffusion coefficient, h the thickness of the sample and $\frac{\mathrm{d}M_t}{\mathrm{d}\sqrt{t}}$ is the slope of the weight gain vs. square root of time relation (in the linear region). Since the D_A given by Equation (3) does not account for diffusion through edges of samples, Rao et al. [26] proposed a geometric edge correction factor to calculate the true diffusion coefficient (D) by taking in to account moisture penetrating through the specimen edges:

$$D = \frac{D_A}{\left[1 + \frac{h}{L} + \frac{h}{W}\right]^2} \tag{3}$$

where L and W are the length and width of samples, respectively.

Mechanical properties

The flexural properties were measured according to ASTM D 790 test method A. Three-point bending tests were carried out on samples whose dimensions were: 127 mm long × 12.7 mm wide × 3.2 mm thickness. The support span was 51.2 mm resulting in a span-to-depth ratio of 16. The cross head speed was set at 1.36 mm/min. Real-time load and displacement data was used to determine the modulus of rupture (MOR), modulus of elasticity (MOE) and strain at maximum load. Calculation of MOE was based on the data within the linear region of the load–displacement curve, which was found to be within 20–40% of maximum load for all treatments.

Flexural tests were performed both in control and wet conditions. During the water immersion period, temperature of water was maintained at $23 \pm 1°C$. The control test samples were conditioned to $23 \pm 2°C$ and $50 \pm 5\%$ RH for 40 h prior to the testing. For 'wet state' tests, the samples were taken directly out of the water after being immersed in water for a set amount of time. Before the tests, excess water was wiped off from the samples. The samples were submerged in water for intervals of 4 and 12 weeks to determine the impact of water on the mechanical properties. Three specimens were tested for each treatment group.

Statistical analyses

A three way analysis of variance model was used to study the effect of heat treatment temperature, coupling content, and time on the evaluated properties. The GLM procedure of the SAS program was used and pairwise comparisons were then made using protected Fisher LSD (least significant difference). Correlations and regressions between MOR, MOE, and water sorption were calculated as well.

Results and discussion

Water sorption

Water sorption of composites after 10, 25, and 40 weeks immersion in water are shown in Table 2. Statistical analyses show that the coupling agent content and pre-treatment temperatures significantly affected the water sorption. Pre-treatment of wood in proper temperatures could reduce water sorption in the composites (Table 2). Using wood treated at 190°C and 205°C lowered the water sorption as high as 18%. Treating wood at 175°C did not change water sorption as the composites absorbed water as if they were untreated wood (formulations nos. 3 (0C/175T) and 1(0C/0T)). Degradation of hemicelluloses, which are the most hydrophilic components of wood, during the pre-treatment, can explain the reduction in water sorption of the composites. Angles et al.[27] reported that degradation of hemicelluloses has positive effects on reducing water sorption of PP/wood composites.

Despite more degradation of hemicelluloses at 205°C than 190°C, composites made of wood treated at 205°C (formulation no. 7 (0C/205T)) had higher water sorption values than composites having wood treated at 190°C (formulation no. 5 (0C/190T)) (Table 2). The higher water sorption of formulation no. 7 (0C/205T) was related to effects of the temperature of pre-treatment on wood. Treating wood at 205°C resulted in formation of char in the surface of wood. Since char has a more porous structure than wood,[28] using slightly charred wood as filler in composites led to high water sorption as seen in formulation no. 7 (0C/205T).

Introducing 2% coupling agent to the formulation of composites decreased water sorption as high as 57% (Figure 1). The effects of the coupling agent in bringing down water uptake are more apparent in composites consisting of untreated wood (formulation no. 2 (2C/0T)) (Figure 2). The effects of adding the coupling agent were less noticeable in wood treated at 190°C and 205°C (formulations nos. 6 (2C/190T) and 8 (2C/205T)). Many types of coupling agent have been developed to improve the interfacial bonding of the two different phases.[29] The most common of them is maleic anhydride grafted polyolefin (MAPO). This coupling agent works by two different mechanisms. First, the anhydride reacts with a cell wall polymer hydroxyl group to form an ester bond, then the polyolefin chain attached to anhydride interacts with the matrix polymer presumably through chain entanglement. Via adhesion mechanisms, the coupling agent enhanced the mechanical properties of the composite. Typically, the inclusion of either a PP and PE chain on the MAPO is selected to match the matrix polymer. However, Chowdhury and Wolcott[29] have found that maleated polypropylene (MAPP) works well with either PP or HDPE composites.

Thickness swelling

Figure 3 shows thickness swelling of the formulations, after the samples were immersed in water for 40 weeks. Coupling agent content and pre-treatment temperatures significantly affected the thickness swelling (Table 3). Using wood treated at 190°C and 205°C resulted in substantial reduction of thickness swelling. Decrease in hygroscopic character of wood and better interfacial adhesion[30] could explain the reduction.

In composites with untreated wood, the effect of adding the coupling agent on reducing thickness swelling was more prominent. Yang et al.[31] reported that inclusion of a coupling agent had a positive effect on dimensional stability of the composites stemming from improved interfacial bonding between hydrophilic fibers and hydrophobic polymers. The results demonstrated that treating wood at 190°C and 205°C was

Table 2. Water sorption after 10, 25, and 40 weeks immersion in water

Formulation number	Code	Water sorption after 10 weeks (%)	Water sorption after 25 weeks (%)	Water sorption after 40 weeks (%)
1	0C/0T	6.39	12.31	13.07
2	2C/0T	2.98	4.80	6.03
3	0C/175T	6.05	12.01	12.88
4	2C/175T	3.54	5.60	6.99
5	0C/190T	4.65	9.36	11.44
6	2C/190T	3.02	4.746	5.92
7	0C/205T	5.04	10.10	12.15
8	2C/205T	3.08	4.916	6.11

C, coupling agent content; *T*, heat treatment temperature.

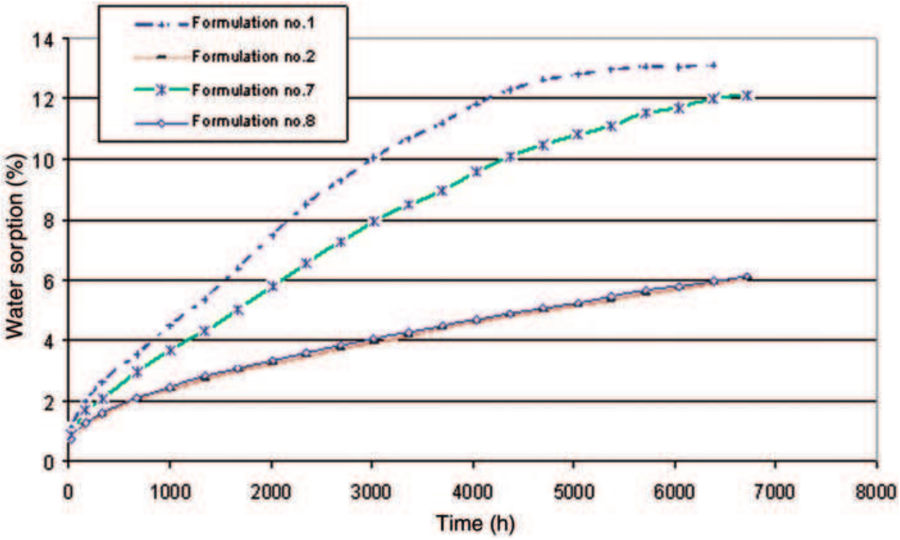

Figure 2. Effects of adding coupling agent on water sorption of composites (formulation no. 1: untreated wood, MAPP: 0%; formulation no. 2: untreated wood, MAPP: 2%; formulation no. 7: wood treated at 205°C, MAPP:0%; formulation no. 8: wood treated at 205°C, MAPP:2%).

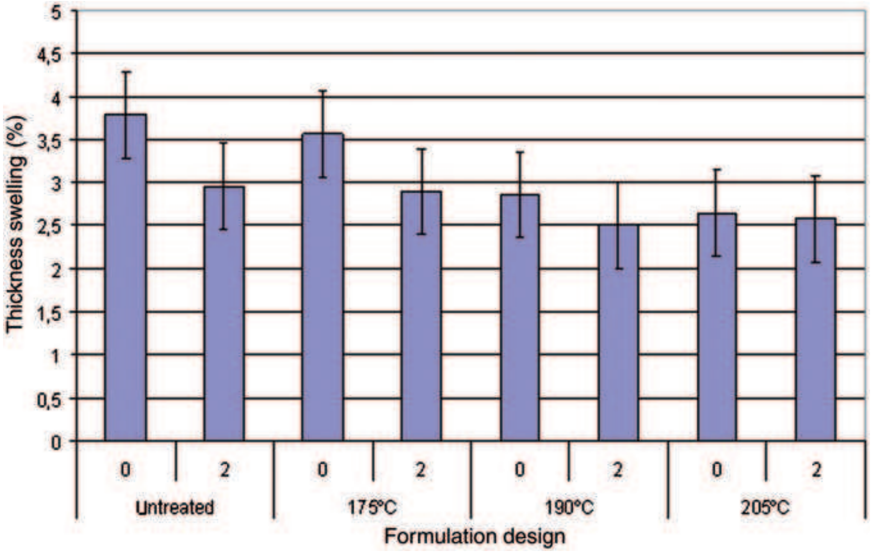

Figure 3. Values of thickness swelling after 40 weeks immersion in water for the formulations (first and second lines of *x*-axis are coupling agent content and pre-treatment temperatures, respectively).

Table 3. Summery of statistical analyses preformed on the data of water sorption tests

	Water sorption		Thickness swelling		Diffusion coefficient	
Variable factor	*F*-values	*P*-values	*F*-values	*P*-values	*F*-values	*P*-values
Coupling agent content	3814.3	<0.0001**	790.56	<0.0001**	135.00	<0.0001**
Pre-treatment temperature	79.19	<0.0001**	454.19	<0.0001**	122.44	<0.0001**

**Significance at 1% level.

more efficient than adding coupling agent in reducing thickness swelling (formulations nos. 2(2C/0T), 5(0C/190T), and 7(0C/205T)).

Diffusion coefficients

In Figure 4, for formulations nos. 1 and 3, the process of water sorption by the composites follows kinetics and mechanisms described by Fick's law. Other researchers[5,7,10,24] also reported that the mechanism of water sorption in WPCs followed a model proposed by Fick.

Diffusion coefficients for the formulations are given in Table 4. Coupling agent content and pre-treatment temperature significantly affected the diffusion coefficients (Table 3). Using wood treated at 190°C and 205°C caused a reduction in diffusion coefficients (formulations nos. 5 (0C/190T), and 7(0C/205T)). Decrease in hygroscopicity of wood and improvement on interfacial adhesion [30] could cause the reduction. Due to negligible effects of pre-treatment at 175°C on wood, composites containing wood treated at 175°C had diffusion coefficients close to untreated wood/HDPE composites (formulations nos. 3(0C/175T), and 1(0C/0T)). Adding 2% coupling agent to the composites led to a decrease in diffusion coefficients. Stamboulis et al.[10] and Espert et al.[9] found out that adding coupling agent to the composites reduced diffusion coefficients. The reduction was attributed to better adhesion between wood and matrix caused by coupling agent.

Treating wood at 190°C and 205°C improved water resistance of composites. After a 40-week period of immersion in water, wood/HDPE composites showed

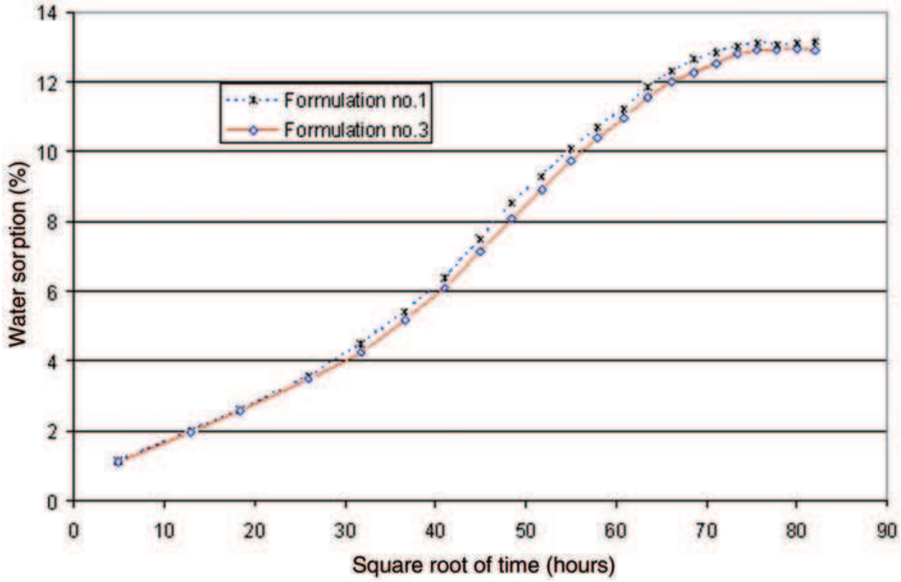

Figure 4. Relationship between water sorption and time (formulation no. 1: untreated wood, MAPP: 0%; formulation no. 3: wood treated at 175°C, MAPP: 0%).

Table 4. Apparent and true diffusion coefficients

Formulation number	Code	Apparent diffusion coefficient (mm^2/s)	True diffusion coefficient (mm^2/s)
1	0C/0T	1.8798E-07	1.0912E-07
2	2C/0T	6.6796E-08	3.8772E-08
3	0C/175T	2.3418E-07	1.3593E-07
4	2C/175T	6.9487E-08	4.0334E-08
5	0C/190T	1.47524E-07	8.56307E-08
6	2C/190T	5.72759E-08	3.3246E-08
7	0C/205T	1.48051E-07	8.59369E-08
8	2C/205T	7.73619E-08	4.4905E-08

C, coupling agent content; *T*, heat treatment temperature.

very low thickness swelling compared to wood-based panels such as, OSB, particleboard, and medium density fiberboard (MDF). Wood-based panels experience high amounts of thickness swelling over a short period of time (as little as 2 h) in water. Using wood, treated optimal both in temperature and environmental conditions, as filler in thermoplastic composites can be an excellent strategy to strengthen water resistance of the composites and open new markets for composites with high wood contents.

Mechanical properties

The values of MOR before and after water exposure for 4 and 12 weeks are given in Figure 5. The variations in MOR due to different amounts of water exposure did not produce any significant difference between the formulations (Table 5). Surprisingly, immersion in water for 4 weeks increased MOR. The increase was evident in formulations with no coupling agent. The highest increase was observed in formulation no. 5 (7.64%) having wood treated at 190°C and no coupling agent. Wood swelling caused by water sorption may fill the gap between wood and the matrix, which can lead to an increase in MOR. Also, an increase in MOR can be attributed to the fact that the reduction of interfacial strength due to water penetration into interfacial region makes the composites behave in a less brittle manner, which can lead to a higher strength for the composites. Lin et al. [4] reported that the less amount of water sorption is beneficial to mechanical properties of WPCs.

Regardless of the wood pre-treatment conditions, composites with 2% coupling agent had negligible MOR loss. Graft copolymers, such as MAPP, have proved to be suitable additives for cellulosic fibers

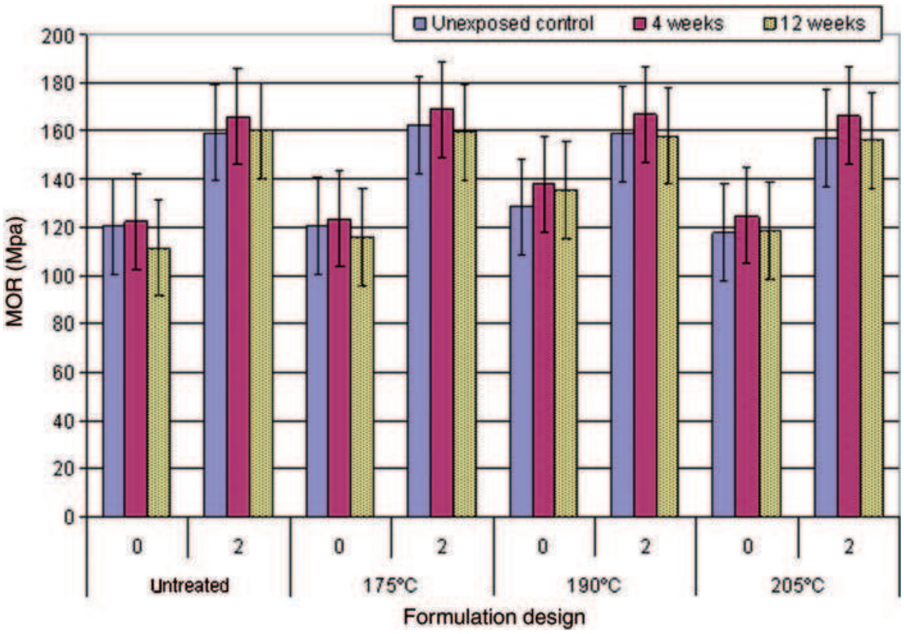

Figure 5. MOR of composites in unexposed control and after water exposure (first and second lines in *x*-axis are coupling agent content and pre-treatment temperature, respectively).

Table 5. Summery of statistical analyses preformed on the data of mechanical test

	MOR		MOE		Strain at maximum load	
Variable factor	*F*-values	*P*-values	*F*-values	*P*-values	*F*-values	*P*-values
Coupling agent content	0.00	*	51.21	<0.0001**	31.84	<0.0001**
Pre-treatment temperature	2.55	*	3.58	0.0185***	1.76	0.1635*

*Not significant.
**Significance at 1% level.
***Significance at 5% level.

reinforced with PP and PE. They form covalent and hydrogen bonds, which improve the fiber/matrix interfacial adhesion.[32–34]

Using wood treated at 190°C and 205°C in composites does not require the coupling agent to reduce the MOR loss. Despite spending 12 weeks in water, formulations nos. 5 (0C/190T) and 7 (0C/205T) showed no loss in MOR even though they did not contain a coupling agent. After spending 12 weeks on water, formulation no. 1 (0C/0T) experienced the highest loss (7.357%). Taib et al.[8] mentioned that the interaction of water molecules with the fiber cell wall via the formation of hydrogen bonding and creations of micro cracks caused by fiber swelling resulted in mechanical loss in *acacia mangium* fiber–PP composites after immersion in water.

Using heat-treated wood as filler reduced the effects of water on MOR. Heat treatment of wood at 175°C decreased the MOR loss to 3.876% (formulation no. 3 (/0C/175T)). Formulation no. 5 (0C/190T) with wood treated at 190°C had a reasonable MOR value for the control state test and minimal MOR loss, compared to both the control and wet state MOR values.

Figure 6 gives the values of MOE of WPCs due to immersion in water. Effect of pre-treatment temperature and coupling agent content on MOE loss is significant (Table 5). Four weeks water exposure did not negatively affect MOE of composites with 2% coupling agent. However, formulation no. 1 (0C/0T) having no coupling agent and treated wood suffered a high loss (9.3%). Using heat-treated wood alleviated the loss of MOE drastically. Reductions in MOE were less evident in composites with 2% coupling agent and treated wood. The extent of improvement in composites in terms of MOE loss depends on the temperature of the heat treatment. Formulation no. 5 (0C/190T) showed 12.466% MOE loss which is approximately equal to MOE loss of formulation no. 2 (2C/0T) (11.821%). In other words, proper pre-treatment of wood and adding 2% coupling agent can reduce the MOE loss in the same scale.

Formulation no. 3 (0C/175T) showed high MOE loss like formulation no. 1 (0C/0T) after a 12-week immersion in water. It seems that treating wood at 175°C has no effects on water resistance of WPCs. As higher temperatures make the wood less hydrophilic,[35] wood treated at 205°C should be less hydrophilic than other samples treated at lower temperatures. Although composites with wood treated at 205°C had less hydrophilicity, the composites suffered higher MOE loss than formulation no. 5 (0C/190T) whose wood was treated at a lower temperature and more hydrophilic (190°C). This phenomenon should be related to effects of heat treatment temperatures on wood. Wood treated at 205°C was charred to some degree as a result of the heat treatment. Char of wood is more porous than wood.[28] The porous structures enable water molecules to penetrate into wood easily and provide water molecules with more space. When wood treated at 205°C was used as filler at

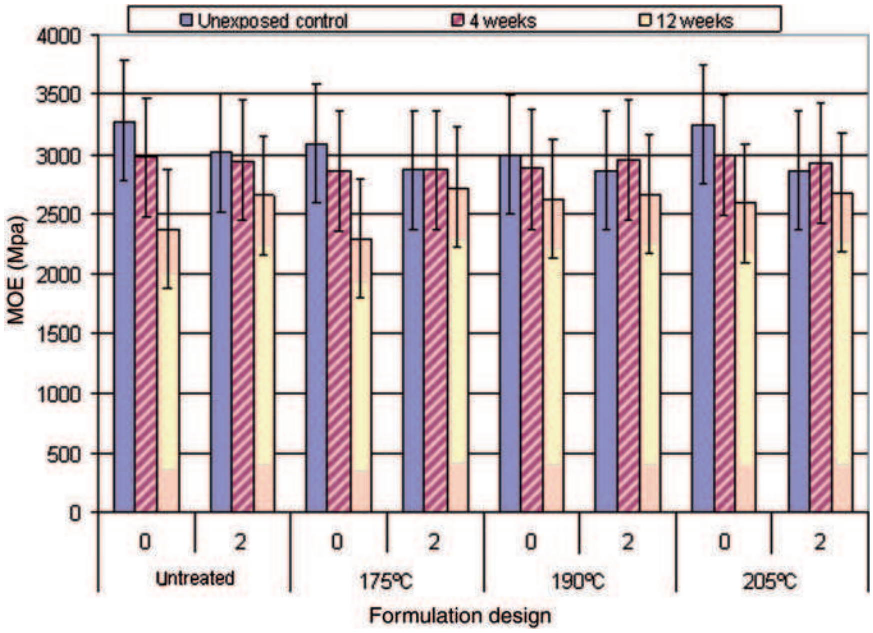

Figure 6. MOE of composites in unexposed control and after water exposure (first and second lines in *x*-axis are coupling agent content and pre-treatment temperature, respectively).

50% level with HDPE, the composites could absorb a considerable amount of water due to the porous structures of wood. As water sorption and MOE measurements showed, despite being less hydrophilic, using wood treated in 205°C at 50% level (formulation no. 7) led to higher water sorption and MOE loss.

Calculations of correlations and regressions between MOR, MOE, and water sorption (Table 6) showed that the relation between water sorption and changes in MOE was stronger than the relation between water sorption and changes in MOR. As shown in Figures 5 and 6, MOE was more sensitive towards water exposure than MOR. Immersion in water caused significant MOE loss, meanwhile, MOR was affected by water exposure in much less degree. Huang et al.[36] found that the effects of water on MOE are more severe than MOR.

Figure 7 shows values of strain at maximum load due to immersion in water. Among the variable factors, coupling agent content had significant effects on strain at maximum load changes (Table 5). Immersion in water increased strain at maximum load up to 35%. Both coupling agent content and wood pre-treatment temperature were important to estimate the extent of changes caused by water exposure. Using wood treated at 190°C and 205°C reduced the increase in strain at maximum load occurred after 4 weeks exposure to water, in comparison with wood without heat treatment and treated at 175°C.

Strain at maximum load measured after 12 weeks submerged in water showed that strain at maximum load of formulation no. 5 (0C/190T) was affected less by water exposure compared to other formulations. Although wood treated at 205°C is less hydrophilic, those composites showed a higher increase in strain at maximum load after immersion in water than formulation no. 5 (0C/190T). High water sorption of the composites could explain the behavior. Joseph et al.[24] reported that water exposure caused an increase in strain at maximum load because of the plasticization effect of water.

Table 6. Correlation coefficients and regressions between MOR, MOE, and water sorption

	Water sorption	MOE loss	MOR loss
Water sorption	1.00000	−0.86894 (<0.0001)	−0.28036 (0.0057)
MOE loss	−0.86894 (<0.0001)	1.00000	0.32254 (0.0014)
MOR loss	−0.28036 (0.0057)	0.32254 (0.0014)	1.00000

Prob > |r| under H0: Rho = 0.

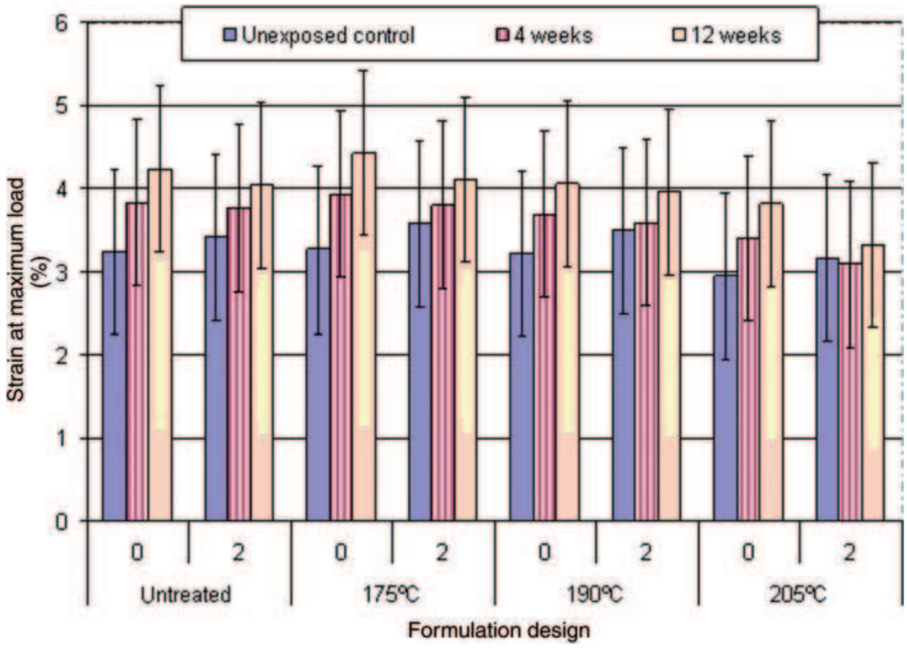

Figure 7. Strain at maximum load of composites in unexposed control and after water exposure (first and second lines in *x*-axis are coupling agent content and pre-treatment temperature, respectively).

Generally, the addition of coupling agent in the formulations reduced the fluctuations in strain at maximum load caused by immersion in water. Using heat-treated wood curtailed the effectiveness of the coupling agent on the fluctuations. Using wood treated at 205°C as filler along with coupling agent reduced the change in strain at maximum load to as low as 5.1%.

With the increasing interest for use of WPCs in exterior applications, it further enforces the importance to produce WPCs with high water resistance that can retain their mechanical properties in short and long terms water exposure. Improvement on water resistance and mechanical integrity of composites obtained by heat treatment of wood is significant. Heat treatment of wood can be used as a way to produce durable WPCs. The results of this study show the potential usage of heat treatment on wood and its benefits to water resistance in terms of mechanical properties. In order to explore the benefits of using heat-treated wood as filler in plastic industries completely, some techniques should be developed for heat treatment of wood flour. The current heat treatment techniques used for wood have been developed primarily for solid wood. To use the benefits of heat treated wood as filler, specialized heat treatment techniques need to developed and introduced to the industry, which will eventually lead to the commercialization of heat-treated wood/thermoplastic composites.

Conclusions

In this study, water resistance of thermally modified wood/HDPE composites were examined by measuring water sorption, thickness swelling, diffusion coefficients, and mechanical integrity of WPCs. Wood treated with appropriate temperatures and amount of coupling agent, lowered water sorption, thickness swelling, and diffusion coefficients. In the case of thickness swelling, effects of pre-treatment of wood were more efficient than adding an agent coupling. Wood heat treatment was found to be an effective way to reduce the negative effects of water exposure on mechanical properties of WPCs. An increase in MOR after short-term water exposure displayed the benefits of small amount of water sorption for MOR. For long-term exposures, the heat treatment of wood was effective in reducing the MOR loss caused by water sorption. Composites with wood treated at 190°C and 205°C experienced no MOR loss after 12 weeks of water exposure. MOE loss as a result of immersion in water was more severe than MOR loss. In order to fully use the benefits of the treated wood, the treatment should be conducted in a proper temperature. Considering, MOE loss as a result of water exposure, the effects of proper pre-treatment of wood was equivalent to adding 2% coupling agent. Heat treatment of wood at 190°C resulted in composites with the capability of maintaining its mechanical integrity in humid conditions. Strain at maximum load of composites increased after immersion in water. Using wood treated at 205°C as filler with coupling agent reduced the increase in strain at maximum load to as low as 5.1%. Improvement on water resistance and mechanical integrity of composites obtained by heat treatment of wood is significant. Heat treatment of wood can be used as a way to produce durable WPCs. In order to materialize the benefits of using heat-treated wood as filler in plastic industries completely, some techniques should be developed for heat treatment of wood flour. The current techniques existing in the industries have been developed for heat treatment of solid wood only. Any attempt to introduce and develop techniques specialized for heat treatment of wood flour could lead to fully implementing the benefits of heat-treated wood as filler and eventually commercializing heat-treated wood/thermoplastic composites.

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