Effect of Particle Pre-treatments on the Quality of Kenaf Core/HDPE Plastic Composites

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Kenaf (*Hibiscus cannabinus*) produces a highly versatile fiber with a variety of uses, but it also produces sizable amounts of core materials that have fewer value-added applications. One possible use for the plant core is in plastic composites, but developing suitable interactions between the hydrophobic plastic and the hydrophilic kenaf core is difficult. In this study, the potential for using various kenaf core pre-treatments was explored using high-density polyethylene (HDPE). While the pre-treatments changed the pectin content and lignin content, the increase or decrease depended on the pre-treatment methods. Pretreatments of core particles with 1% NaOH for 60 min or 1% HCl for 30 min markedly improved the mechanical properties of a 60/40 kenaf/HDPE mixture, although the pre-treatment had little effect on resistance to fungal attack. The results suggest that pectinase enzyme or cellulase enzyme pretreatment time should be shortened to 30 min or 60 min.

Keywords: Kenaf; Hibiscus cannabinus; High density polyethylene (HDPE); Low density composites; Water sorption; Flexural properties; Decay resistance

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INTRODUCTION

Wood/plastic composites (WPC's) represent an increasing share of the North American decking market (Clemons 2002). These materials typically use 40 to 60% wood powder with either high density polyethylene (HDPE) or polypropylene (PP) plus various coupling agents. Cellulosic fibres are added to provide stiffness and reduce density, but short-comings of this material include an inability to interact substantially with the plastic component owing to the hydrophobic nature of the plastic *vs.* the hydrophilic characteristics of the cellulosic materials and the inherent susceptibility of the wood to biodegradation (Lu *et al.* 2000; Mankowski and Morrell 2000; Wang and Morrell 2004, 2005; Morrell *et al.* 2006; Huang *et al.* 2015; Ma *et al.* 2017).

One way to alter the cellulose/plastic relationship is to modify the cellulosic fibres to make them more compatible with the plastic (Bouafif *et al.* 2009; Meon *et al.* 2012; Wei *et al.* 2013). There are a variety of possible candidates for modification, but one of the more attractive is kenaf (*Hibiscus cannabinus* L.). Originally from Southeast Asia, kenaf produces long, high-strength fibres that can be used in a variety of applications (Rowell *et al.* 1997a). Kenaf also produces a core containing shorter fibres that are used for animal bedding and other low value applications (Sellers *et al.* 1993; Xu *et al.* 2004; Villr *et al.* 2009; Nourbakhsh and Ashori 2010; Elsaid *et al.* 2011; Chan *et al.* 2013). Modified kenaf core material may also be useful in plastic composites because it has a lower lignin content

than traditional wood materials, and this may make it more suitable for modification (Rowell *et al.* 1997b; Ajil *et al.* 2009; Akil *et al.* 2011). Sodium hydroxide, coupling agent, and laccase enzyme were used to modify kenaf fibers to make composites of higher quality (Ajil *et al.* 2009; Islam *et al.* 2011; Meon *et al.* 2012), but there is little information about pectinase enzyme, cellulase enzyme, and acid pretreatment on the properties of kenaf-core particles /HDPE composites.

The biodegradability of composites has important implications regarding the environment (Pang *et al.* 2017), but there is little information about kenaf/ HDPE composites. Accordingly, this work considered the biodegradability properties of pretreated kenaf/HDPE composites when subjected to three kind of fungus. The goal of this work was to explore the potential for modifying kenaf core material prior to incorporation into an HDPE composite.

EXPERIMENTAL

Kenaf Particle Preparation

Kenaf core stock was obtained (Bio-Sorb, KenGro Corp, Charleston, MS, U.S.A.) as chips measuring 3 to 10 mm long by 2 to 5 mm wide and had been dried prior to arrival. Chips were boiled for 24 h in distilled water, and the resulting mixture was blended in a L5MA lab mixer (Silverson Machines Inc., Longmeadow, MA, USA) to reduce the material to slivers measuring 1 to 2 mm long by 0.2 to 0.3 mm wide. The material was divided into seven groups each containing 25 g of particles and these groups were assigned to the various treatments. One group was retained as a non-treated control.

Kenaf Particle Pre-treatments

Batches of boiled and dried kenaf particles (25 g each) were subjected to a variety of pre-treatments as follows: (1) cellulase enzyme from *Aspergillus* species for 3 h to disrupt the lignocellulose matrix and enhance HDPE interactions; (2) pectinase enzyme from *Aspergillus* species for 3 h to disrupt the middle lamella between cells and create more fibre surface area; (3) 1% NaOH for 30 min or 60 min to disrupt the lignin and hemicellulose matrix to increase fibre surface area (Demirba 1998); and (4) 1% HCl for 30 min or 60 min to disrupt and degrade cellulose and hemicellulose for increasing fiber surface area (Kalapathy and Proctor 2001). In all cases, 25 g of dry fibre was dispersed in 500 mL of the treatment solution and heated at 50 °C. The solution was decanted, and the residual fibres were washed several times with distilled water to remove residual reactant till the pH of the rinsate was 7.0. The treated particles were oven dried at 104 °C prior to use.

Lignin and Pectin Content

The effect of pre-treatment on lignin and pectin in kenaf chips was determined by grinding the fibers and collecting fibres that passed through a 40-mesh screen but not a 60-mesh screen. The resulting powder was used to determine pectin and Klason lignin content using previously described procedures (GB/T 10742-2008 2008; ASTM D-1106 2015) (Table 1) (Li *et al.* 2017). Lignin content was determined gravimetrically by sulfuric acid digestion. Pectin was determined by sequential extraction in 1:1 benzene alcohol, 1% ammonium oxalate, and finally 0.5% ammonium oxalate. The resulting residual solid material was washed with boiling 2% ammonia in ethanol several times to produce

approximately 250 mL of solution. Pectin was analyzed following the method described by Bitter and Muir (1962), wherein 1 mL of solution was added to 8 mL of concentrated sulfuric acid and incubated for 15 min at 75 °C. The solution was cooled, then 0.2 mL of 0.15% carbazole in ethanol was added to the mixture and allowed to stand for 2 h. Absorption was measured at 530 nm, and the values were compared with similar solutions prepared using known amounts of pectin.

Kenaf Core Particle/HDPE Panel Production

The original and modified kenaf fibers were used to produce panels with HDPE pellets at ratios of 60:40 or 40:60 percent based on mass. Sets of panels were also manufactured using 40 or 60 % non-modified kenaf along with 3% silane. The silane was added to facilitate kenaf/HDPE interactions. The mixtures were placed into a Brabender Intelli-torque Plasticorder (C.W. Brabender Instruments, Hackensack, NJ, USA) and thoroughly mixed before being removed and allowed to cool. The cooled mixture was then ground to pass a 20-mesh screen and formed into 50 by 12 mm by 2 mm thick mats in a mold. The mats were pressed for 10 min at 150 °C to a target density of 0.83 g/cm^3. Twenty samples were produced for each mixture. The resulting samples were used directly for flexural tests, cut in half lengthwise to produce 25 by 12 mm wide samples for water absorption/thickness swelling tests or cut into 10 by 12 mm sections for decay tests.

Panel Properties

The bending samples were tested to failure in third point loading at a rate of 1 mm/min on a universal testing machine according to procedures described in ASTM D790-02 (2002). The resulting load/deflection data were used to calculate modulus of elasticity (MOE) and modulus of rupture (MOR).

Water absorption and thickness swell were assessed by weighing each section and measuring panel thickness before and after 24 h of water immersion at 20 °C. Differences between pre- and post-immersion mass and thickness were used to calculate the water absorption and thickness swelling, respectively (EU 2015).

Decay Resistance

Wood plastic composites tend to be more resistant to decay than the parent wood because the HDPE tends to enhance water resistance, but the lower lignin content of kenaf could make the panels more susceptible to fungal attack. Decay resistance was assessed according to procedures described in AWPA Standard E10 (2017). The test samples were oven dried (50 °C) and weighed to the nearest 0.001 g. The materials were soaked in distilled water until their moisture contents were between 20% and 40%, and then they were sterilized by heating at 121 °C for 25 min.

Decay chambers were prepared by half filling 454 mL French squares with moist forest loam and placing a western hemlock (*Tsuga heterophylla* Raf. Sarg.) (brown rot fungi) or red alder (*Alnus rubra* Bong.) (white rot fungus) feeder strip on the soil surface. The bottles were then loosely capped and autoclaved for 80 min at 121 °C. After cooling, the bottles were inoculated with 3 mm diameter malt agar disks cut from the actively growing edges of cultures of the test fungi. The fungi evaluated in these procedures were *Gloeophyllum trabeum* (Pers. ex. Fr.) Murr. (Isolate # Madison 617), *Rhodonia placenta* (Fr.) (Isolate # Mad 698), or *Trametes versicolor* (L. ex Fr.) Pilát (Isolate # R-105). The first two fungi produce brown rot, while the latter species causes white rot. The agar plugs were placed on the edges of the wood feeder strips, the jars were loosely capped to allow

air exchange and were incubated until the feeder strip was thoroughly covered with fungal mycelium. The sterile test samples were then placed on the surfaces of the feeder strips, the bottles were loosely capped and incubated at 28 °C for 12 or 16 weeks for blocks exposed to brown or white rot fungi, respectively. Each treatment was evaluated on 6 samples per fungus.

At the end of the incubation period, the samples were removed, scraped clean of adhering mycelium and weighed to determine wet weight for moisture content. The samples were then oven dried (50 °C) and reweighed to determine mass loss. The difference between initial and final oven-dry weight was used as a measure of the decay resistance of each material.

Data Analysis

All data were subjected to an Analysis of Variance, and then the water absorption and thickness swelling means were examined for significance using Tukeys' Least Significant Difference Test (α=0.05).

RESULTS AND DISCUSSION

Lignin and Pectin Content

The average lignin content of the non-treated kenaf chips was 20.4% (Table 1). While lignin contents trended slightly lower in the pectinase enzyme, cellulase enzyme, and NaOH treated samples, the differences were small. The lack of substantial lignin loss with sodium hydroxide treatment was surprising given the effect of alkali solutions on lignin; however, the concentrations used were relatively low.

The average pectin content was 4.76% in the non-treated controls (Table 1). Pectin levels were lower in samples subjected to either cellulase or pectinase pre-treatment as well as in samples subjected to hydrochloric acid treatments. The lower levels of pectin in cellulase and hydrochloric acid pre-treatments is consistent with the premise that these treatments should affect the carbohydrate fractions, thereby proportionally increasing the amount of residual pectin. The pectinase treatment should have obvious effects on pectin levels (Li *et al*. 2018). Pectin levels were higher in NaOH treated samples, but the results were variable. The lack of concurrent lignin loss suggests that this treatment did not consistently affect either pectin or lignin content.

Table 1. Effect of Pre-treatment of Kenaf Core Particles on Pectin and Lignin Content [a]

Kenaf Pre-treatment	Lignin Content (%)	Pectin Content (%)
None	4.76 (0.57)	20.44 (1.58)
Cellulase	3.43 (0.35)	18.79 (2.31)
Pectinase	3.80 (0.71)	19.86 (2.30)
NaOH (0.5 h)	5.41 (0.17)	19.58 (0.51)
NaOH (1.0 h)	5.51 (1.64)	19.84 (1.78)
HCl (0.5 h)	3.35 (0.57)	21.03 (0.80)
HCl (1.0 h)	3.20 (1.11)	21.44 (1.43)

[a]Values represent means of triplicate analyses while figures in parentheses represent one standard deviation.

Water Absorption and Thickness Swell

In general, composites made containing cellulosic materials coupled with HDPE have sharply reduced water uptakes compared to the original cellulosic material, and the kenaf/HDPE panels closely followed this trend. Water absorption decreased by approximately 50% as the HPDE content was increased from 40 to 60%, reflecting the likelihood that increased HDPE content better protected the kenaf particles from wetting (Table 2). Pre-treatment of kenaf particles prior to panel manufacturing was associated with increased water absorption for all panels made with 60 % kenaf. Panels with kenaf particles pre-treated with cellulase, pectinase, or 1% NaOH for 30 min experienced the largest increases, while those pre-treated for 30 min with HCl experienced minimal change in water uptake compared to the non-modified kenaf control. Even the addition of silane as a coupling agent was associated with increased water uptake, and the results were not similar to previously reported results (Ajil *et al.* 2009). This may be because the ratios of kenaf particles in these composites were too high. The results suggest that enzymatic or chemical pre-treatment of kenaf particles enhances their hygroscopicity.

Water absorption of panels containing only 40% kenaf was 50 to over 80% lower than that found with the 60% kenaf panels. These results are consistent with the premise that the additional HDPE more completely coats the kenaf particles, thereby reducing the rate of moisture uptake. Particle pre-treatment had more variable effects on water absorption at the higher HDPE level. Addition of silane or pre-treatment with pectinase or HCl was associated with decreased water absorption, while pre-treatment with cellulase or NaOH produced a slight increase in absorption. The more variable effects of pre-treatments on water absorption in panels with more HDPE may reflect the dominance of the water repellency of the HDPE compared to the reduced kenaf content.

Table 2. Effect of Kenaf Pretreatments on Water Absorption and Thickness Swell of Panels Containing Two Different HDPE Levels [a]

Kenaf Pre-treatment	Water Absorption (%)		Thickness Swelling (%)	
	60/40 Kenaf/HDPE	40/60 Kenaf/HDPE	60/40 Kenaf/HDPE	40/60 Kenaf/HDPE
	Actual	Actual	Actual	Actual
None	11.28 (1.49) B	5.80 (1.88) AB	4.98 (1.41) B	1.59 (1.16) BC
Silane	13.40 (2.73) B	4.92 (1.41) AB	6.07 (1.71) AB	1.08 (0.97) C
Cellulase	15.10 (2.81) AB	5.95 (1.76) AB	7.11 (1.52) AB	1.88 (1.01) AB
Pectinase	16.38 (2.22) A	5.11 (1.54) AB	7.61 (1.29) A	1.40 (0.76) C
NaOH(0.5 h)	15.36 (2.18) AB	6.23 (1.86) AB	5.98 (2.46) AB	2.97 (1.13) A
NaOH(1.0 h)	12.53 (2.16) B	6.59 (2.38) A	5.17 (1.70) B	2.66 (1.15) AB
HCl (0.5 h)	11.36 (3.19) B	4.62 (1.18) B	4.23 (5.40) B	1.68 (0.76) BC
HCl (1.0 h)	13.49 (2.25) B	4.47 (1.08) B	7.45 (1.73) A	1.93 (0.74) AB

[a] Values represent means of 10 replicates per treatment. Values in parentheses represent one standard deviation.

Increasing HDPE content from 40 to 60% was associated with reduced swelling for all panels, again reflecting the protective effect of the HDPE on the kenaf particles. Most pre-treatments were associated with increased swelling for the 60% kenaf panels. The exception was with the 30 min 1% HCl specimens, which experienced a 15.1% reduction in swelling, but this effect disappeared when the treatment time increased to 60 min; this may be because the lignin content was reduced to 32.8% but the pectin increased 4.9%. Pectin is known to reduce the hygroscopicity of composite materials (Yang *et al.* 2019).

Acidic treatments should remove accessible carbohydrates that could contribute to swelling, but prolonged exposure may increase accessibility. The addition of silane to the panels or pre-treatment with pectinase produced reductions in thickness swell for panels with 60% HDPE. Sodium hydroxide pre-treatment was associated with substantial swelling increases. This may reflect lignin disruption that, in turn, exposed cellulose to further moisture uptake.

Overall, increased HDPE content had a far greater effect on either water absorption or thickness swelling. Pre-treatments produced more variable effects, but it is important to note that none of the pre-treatments were designed to alter the inherent hygroscopicity of the kenaf particles.

Flexural Properties

MOE did not change appreciably as HDPE content increased from 40 to 60% (Table 3). All of the pre-treatments for panels with 60% kenaf except for the 30 min NaOH and 60 min HCl treatments were associated with increased MOE values. The two treatments for which increases were not noted were similar to the non-treated control. The most interesting effect was the nearly 50% increase in MOE for panels containing kenaf pre-treated for 1 h with NaOH. It is unclear why this treatment was associated with such a large improvement, especially since differences between panels with untreated kenaf and kenaf treated for 1 h with NaOH were minimal in samples with more HPDE. Increasing HDPE content produced variable results. MOE increased in 4 treatments and declined in the remaining four. The effect of pre-treatments was also diminished with 3 treatments (silane additive, pectinase, and the 30 min HCL pre-treatments), while the remainder experienced slight increases. The results suggest that the increased HDPE content diminished the effects of any pre-treatment on properties. The original objective for particle pre-treatment was to improve panel properties. Cellulosic particles are generally added to plastic panels to reduce weight and improve MOE. While it would be difficult to compare the properties of these laboratory prepared panels to those in commercial use, the results indicate that pre-treatment generally produced only slight improvements in this property.

MOR should be affected by the HDPE content, and this was demonstrated when values tended to be higher for samples with more HDPE, except for the 0.5 h HCl treatment, which was slightly lower. Pre-treatments produced more variable results, especially at the lower HDPE level. Pre-treatment with NaOH for one hour or HCl for 30 min produced marked improvements in MOR for panels with 60% kenaf. Six of the seven pre-treatments or additives were associated with increased MOR when HDPE content was increased, but there was no consistent pattern. For example, NaOH pre-treated kenaf was associated with an 82% improvement ion MOR when 40% HFPE was used but only a 44.2% improvement at the higher HDPE level.

The absence of consistent effects suggests that other factors are affecting flexural properties. One factor might be particle size. The particles used in this study were relatively small. While the small size greatly increases the surface area that can interact with the HDPE, the shorter particles may limit any influence of fibers on flexural properties. For 40/60 kenaf/HDPE composites panels, MOR increased dramatically with several kinds of treatment, but the improvements were not the same as for MOE with the exception of the 1% HCl exposure for 60 min.

Table 3. Effect of Kenaf Pretreatments on Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) of Panels Containing Two Different HDPE Levels[a]

Kenaf Pre-treatment	Modulus of Elasticity (MPa)				Modulus of Rupture (MPa)			
	60/40 Kenaf/HDPE		40/60 Kenaf/HDPE		60/40 Kenaf/HDPE		40/60 Kenaf/HDPE	
	Actual	%Diff	Actual	%Diff	Actual	%Diff	Actual	%Diff
None	3012.8(596.6)	-	3134.5(751.9)	-	14.06(3.06)	-	17.98(2.51)	-
Silane	3509.1(557.1)	+16.5	2958.4(506.4)	-5.6	17.02(2.97)	+21.1	19.42(4.08)	+8.0
Cellulase	3243.2(397.3)	+7.6	3267.5(427.8)	+4.2	13.14(2.56)	-6.5	23.01(3.32)	+28.0
Pectinase	3146.3(590.6)	+4.4	2700.0(626.3)	-18.9	12.82(3.23)	-8.8	19.65(3.77)	+9.3
NaOH(0.5h)	2892.9(571.6)	-4.0	3197.3(459.3)	+2.0	14.22(2.96)	+1.1	24.01(5.56)	+33.5
NaOH (1.0h)	4504.0(589.6)	+49.5	3210.7(638.3)	+2.4	25.53(4.85)	+82.1	25.93(7.10)	+44.2
HCl (0.5h)	3366.0(767.9)	+11.7	2753.8(476.3)	-12.2	19.89(4.82)	+41.5	17.84(2.34)	-0.8
HCl (1.0h)	3002.2(759.9)	-0.4	3314.0(678.3)	+5.7	14.17(2.60)	+0.8	24.23(5.43)	+34.8

[a]Values are means of 10 replicates per treatment. Values in parentheses represent one standard deviation.

While 1% NaOH exposure for 60 min, 1% HCl exposure for 30 min, and silane coupling agent had marked effects on MOE and MOR of 60/40 kenaf/HDPE composites, the results were in line with the previous results (Li *et al.* 2018). Pectinase enzyme and cellulase enzyme pre-treatment only improved the MOE of 60/40 kenaf/HDPE composites a little. This may be because the pretreatment time was 3 hours, and the best pretreatment time was 30 min in previous studies (Li *et al.* 2017); another reason is that the raw materials used in this research was small particles, not the fibers (Fig. 4).

Decay Resistance

Untreated pine control blocks experienced substantial weight losses when exposed to either *O. placenta* or *G. trabeum*, but only 25% weight loss was observed when they were exposed to *T. versicolor* (Table 4).

Table 4. Effect of Pretreatment of Kenaf used in Kenaf/HDPE Panels on Resistance to Fungal Attack as Measured Using a Modified American Wood Protection Association E10 Soil Block Test[a]

Chip Pre-Treatment	Mass Loss (%)[a]					
	60% kenaf/40% HDPE			40% kenaf/60% HDPE		
	O. placenta	*G. trabeum*	*T. versicolor*	*O. placenta*	*G. trabeum*	*T. versicolor*
SYP control	54.59(3.80)	71.48(3.32)	25.02(5.87)	-	-	-
None	16.68(3.49)	38.01(5.84)	5.88(1.50)	6.88(1.97)	12.63(1.79)	1.29 (0.20)
Silane added	19.54(1.39)	34.24(6.39)	11.48(3.85)	6.17(1.30)	22.11(1.04)	1.73 (0.43)
Cellulase	19.93(2.51)	39.94(2.48)	6.83(1.16)	3.18(0.76)	19.98(2.85)	1.57 (0.34)
Pectinase	22.13(3.70)	42.86(1.85)	15.08(2.78)	3.73(0.38)	16.74(2.71)	6.11 (1.11)
NaOH (0.5 h)	30.05(3.91)	41.41(1.07)	29.95(2.78)	6.74(1.21)	19.17(4.46)	15.44 (1.93)
NaOH (1 h)	21.43(5.20)	42.24(2.08)	29.35(4.43)	6.86(0.68)	22.79(4.07)	11.45 (0.65)
HCl (0.5 h)	21.84(2.79)	39.15(4.33)	22.10(3.20)	3.19(0.63)	6.11(0.94)	3.84 (0.48)
HCl (1 h)	22.70(3.26)	42.53(4.08)	26.51(5.69)	3.51(0.80)	12.52(1.91)	4.20 (0.77)

[a]Values represent means of 6 replicates per treatment and fungus. Values in parentheses represent one standard deviation. Mass losses for samples with no fungus ranged from 0.05 to 0.88 % and represent loses that occurred due to sterilization, oven-drying and other procedures associated with the test.

The AWPA Standard requires a minimum mass loss of 40%. Thus, the brown rot results indicate that conditions in the chambers were suitable for aggressive fungal decay. The lower weight losses with the white rot fungus are consistent with a reduced decay capacity for this fungus on conifers. The mass losses noted with the white rot fungus still indicate considerable loss in wood properties.

Wood plastic composites tend to experience reduced weight losses compared to the parent cellulosic material. These differences reflect the tendency for the plastic to surround and restrict moisture movement into the wood particles. This effect is not complete; fungi are still capable of growing through voids in the WPC to attack the wood, but weight losses are substantially lower (Mankowski and Morrell 2000). Mass losses of kenaf/HDPE samples tended to be much lower when exposed to *T. versicolor*. The lower mass losses may reflect the overall decay capability of the isolate, but they were also likely affected by the moisture uptake. White rot fungi tend to require higher moisture contents to cause aggressive decay. The HDPE would have limited initial moisture uptake, delaying the start of any fungal attack. While the samples were exposed to the fungus for an additional 4 weeks, this may still have been inadequate given the inherent resistant to moisture uptake by these materials.

In general, mass losses tended to be lower for samples containing more HDPE, reflecting the combined water repellency and potential encapsulating effect of the polymer on the kenaf particles. Mass losses of panels with 60% kenaf exposed to the brown rot fungi tended to be lower than those for the pine controls but were still higher than would be expected for a plastic composite. Pre-treatments produced no consistent effects against either of the brown rot fungi. Interestingly, pre-treatment of kenaf with either NaOH or HCl was associated with substantial mass losses by *T. versicolor*. In fact, mass losses were slightly higher in samples containing NaOH pre-treated kenaf.

Mass losses tended to be lower in panels with more HDPE, although *G. trabeum* caused substantial mass losses. One objective of the soil block test is to establish threshold for protection against fungal attack. These values are developed by plotting mass loss in the presence of a fungus *vs.* mass losses in similar chambers with no fungus present. In general, mass losses of <3% are typical in chambers without a fungus, and these losses represent the effects of potential leaching into the soil as well as the effects of any heating during sterilization or oven drying. In general, very few panel/fungal combinations were associated with weight losses this low. These results indicate that the test fungi were capable of invading and degrading the kenaf particles. These results are consistent with previous studies of soil burials of kenaf based thermoplastic polyurethane panels (Sapuan *et al.* 2013). Increasing HDPE content improved decay resistance, but it is readily apparent that any kenaf-based composite panel will need to be supplemented with a preservative such as zinc borate or possibly co-extrusion with a single layer of fungal resistant materials (Huang *et al.* 2015) if they are to perform acceptably in exterior exposures.

CONCLUSIONS

1. Pre-treatment of kenaf particles for use in composite manufacturing resulted in variable changes in properties. In general, any the effects of pre-treatment were confounded by the effect of increasing high density polyethylene (HDPE) content.

2. The results suggest that pre-treatment may affect properties, but it would be far simpler to increase the HDPE proportion or modify kenaf particle geometry to produce better HDPE coating to achieve similar results.

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