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Mechanical Properties of Extruded High Density Polyethylene and Polypropylene Wood Flour Decking Boards

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ABSTRACT

In this study, mechanical properties of high density polyethylene (HDPE) and polypropylene (PP)-wood flour composite (WFC) decking boards were evaluated and the effect of maleated polypropylene (MAPP) as a coupling agent was investigated. Decking boards were manufactured using Davis-Standard® WT-94 Woodtruder™. Flexural, tensile and impact properties of the decking boards were evaluated. Fractured surface of samples were also studied using scanning electron microscope. Results showed that PP-WFC decking boards provided higher tensile and flexural properties than HDPE-WFC decking boards. The use of maleated polypropylene (MAPP) coupling agent significantly increased the tensile strength and tensile modulus of both HDPE-WFC and PP-WFC composite decking boards. In the case of flexural properties, MAPP coupling agent slightly increased the flexural strength of HDPE-WFC but did not affect the flexural modulus of HDPE-WFC, and flexural strength and flexural modulus of PP-WFC decking boards. This study showed that MAPP coupling agent can effectively be used as a coupling agent for HDPE base resin. It is believed that this performance is due to the base resin used in this study since it is a narrow molecular weight hexene copolymer HDPE. Both HDPE-WFC and PP-WFC decking boards, even with no coupling agent, provided flexural properties required by the ASTM standard for polyolefin-based plastic lumber decking boards. In the case Izod impact strength, addition of MAPP coupling agent significantly reduced the notched Izod impact strength of the all decking boards. In addition, morphological study showed that compatibility between the wood flour and the plastic matrix were improved with the use of MAPP coupling agent.

Key Words:

maleated polypropylene;
high density polyethylene;
coupling agent;
composites;
decking board.

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INTRODUCTION

Composite materials combine two or more materials to form a new material having different and even better properties than materials by themselves. When the wood (in any form) and plastics are used as two materials, resulted composites are called wood-plastic composites (WPCs) [1,2]. The term "plastics" refers to either thermoset or thermoplastic polymers and both polymers have been used in such composites for several years [1]. However, in this article, the term plastics most often refers to thermoplastics, such as polyethylene, polypropylene, and polyvinyl chloride.

WPCs was patented in Italy around 1920s. In this process, polypropylene and wood flour were extruded to manufacture automotive interior parts [1-3]. There was not much of an interest on this process until one American company implementing this Italian extrusion technology to produce automotive interior substrates [3]. This has followed by other companies to produce various shapes of automotive parts by extruding polypropylene and wood flour mixtures. Recently, WPCs have found application areas other than automotive industry such as siding, fencing, window frames and decking [1-7]. Especially after their use in decking applications, manufacturing of WPCs has seen phenomenal growth in the United States. It is well known that decking has a tremendous market in the USA with approximately 18.5 million m^3 in 2000 [4]. Almost all of this market was dominated by pressure treated lumber. Recently, WPC decking boards have gained almost 20 percent of decking market and it is expected to gain more market share in the near future because of EPA's restriction on the use of pressure treated lumber produced with CCA and its derivatives [4].

Traditionally, plastics industry uses inorganic materials such as talc, calcium carbonate, mica, and glass or carbon fibres to fill and modify the performance of thermoplastics. Inorganic fillers provide rigidity and resistance to temperature [5-7], but it is costly and abrasive to the processing equipment [6-8]. It is reported that in plastics industry about 2.5 billion kg of fillers and reinforcements are used annually and most of them are inorganic fillers [1,9]. Recently, several companies start using wood fibre or/and wood flour as a filler in plastics. The primary advantages of using wood fibres or flours in plastics can be listed as low densities, low cost, non-abrasive nature [1,6,7,10], possibility of high filling levels, low energy consumption, high specific properties, biodegradability, availability of a wide variety of fibres throughout the world, and generation of a rural/agricultural-based economy [8,10,11].

Even though many companies were initially sceptical about the process, WPCs have received considerable attention from wood and plastics industries [1,11]. Initial problems about the WPCs were sensitivity of the wood flour or fibres to the heat and moisture, and the lack of adhesion between polar wood and non-polar thermoplastics. Since degradation temperature of the cellulose is around 200ºC which is well over the melting temperature of many commodity thermoplastics, processing temperature is not an issue during the manufacturing of many WPCs. It is well known that even the small amount of water can cause problems during extrusion process. That is why moisture should be removed from wood flour or fibre before or during the process. In the case of adhesion, understanding of the wood and plastic is necessary.

Plastics are hydrophobic (non-polar) substances that are not compatible with hydrophilic (polar) wood flours and, therefore, cause poor adhesion between plastic and wood flours in composites [1,6,7,11,12]. In order to improve similarity and adhesion between wood-fibres and thermoplastic matrices, several chemicals have been employed [13-22]. Lu et al. [23] classified over forty coupling agents used in WPCs into three groups; organic, inorganic, and organic-inorganic coupling agents. Organic agents include isocyanates, anhydrides, amides, imides, acrylates, epoxies, organic acids, monomers, polymers, and copolymers. Silicates were listed as inorganic coupling agents for WPCs while silanes and titanates were considered as organic-inorganic coupling agents for WPCs. Based on these studies, suitable coupling agents for commodity thermoplastics were determined. Silanes could be the best choice for PVC based WPCs while maleated coupling agents should be preferred for polyolefin based WPCs.

Several studies have investigated the effectiveness of maleated coupling agents in the manufacturing of WPCs. Yang et al. [24] used both maleated polyethylene and maleated polypropylene as a coupling agent for wood flour filled polyethylene composites. They have reported that tensile strength of the composites with maleated polyethylene was superior to the composites with maleated polypropylene. Li et al. [25] also studied polyolefin based coupling agents in HDPE-wood flour composites and concluded that maleated polyethylene provided better tensile and impact properties compared to maleated polypropylene. Similar findings were reported by Lai et al. [26]

and Wang et al. [27]. Researchers believed that performance of maleated polyolefins was strongly dependent on the coupling agent's base resin type. That is why PE-based maleated polyolefins were more effective than PP-based counterparts in improving the strength properties of HDPE-wood flour composites [24-27].

Previously, the effect of maleated polypropylene in the manufacture of HDPE-hexene copolymer based WPCs was not investigated. Yamaguchi et al. [28] reported that polypropylene is miscible in the amorphous region of the polyethylene-hexene copolymers. It is believed that this might help the maleated polypropylene to perform better as a coupling agent in a polyethylene based WPCs. It is the purpose of this study to investigate the effects of maleated polypropylene on the mechanical properties of commercial size HDPE copolymer- and PP homopolymer-wood flour composite decking boards.

EXPERIMENTAL

Materials

High density polyethylene (HDPE) and polypropylene (PP) used in this study were supplied by ExxonMobil Chemical Company (ExxonMobil ®HDPE HD 6605, ExxonMobil®PP 5262). HDPE was a narrow molecular weight hexene copolymer commonly used for industrial applications. Its melt flow index and density were 5 g/10 min (2.16 kg and 190ºC, ASTM 1238) and 0.948 g/cm^3, respectively. PP was a general purpose compression moulding grade polymer commonly used for industrial applications having 2 g/10 min (2.16 kg and 230ºC, ASTM 1238) melt index and 0.92 g/cm^3 density. Selected mechanical properties provided by the manufacturers of PP and HDPE are represented in Table 1. Maleated polypropylene (Polybond 3200) with 1.0 weight % maleic anhydride level was used as a coupling agent. Its melt flow index and density were 115 g/10 min (2.16 kg and 190ºC, ASTM 1238) and 0.91 g/cm^3, respectively. Struktol TPW113 consisting of modified fatty acid esters were used as lubricant. Commercial wood fibres from pine wood (40-mesh size) were used as fillers. All materials were used as received from the manufacturers. Table 2 lists all ingredients and their providers.

Composite Manufacturing

High density polyethylene-wood flour composite (HDPE-WFC) and polypropylene-wood flour composite (PP-WFC) decking boards were produced with and without maleated polypropylene (MAPP) coupling agent. Depending on the formulation, ingredients were extruded into 1.9×12.7×244 cm (¾"x5"x8") decking boards using the Davis-Standard® WT-94 Woodtruder™. This system uses a GP94 94 mm counter-rotating parallel twin-screw extruder (28:1 L/D) and Mark VTM 75 mm single-screw extruder together. Three Colortronics gravimetric feeders supply 75 mm single-screw extruder and 94 mm twin-screw extruder via flood feeding and starvation feeding, respectively. The processing parameters are reported in Table 3.

Property Testing

High density polyethylene-wood flour composite (HDPE-WFC) and polypropylene-wood flour composite (PP-WFC) decking boards were produced with and without MAPP coupling agent and tested in a climate-controlled testing laboratory. Flexural, tensile

Table 1. Some properties of HDPE and PP homopolymers provided by the manufacturers.

	Tensile strength [a] (MPa)	Tensile elongation [b] (%)	Flexural modulus [c] (GPa)	Notched Izod impact strength [a] (J/m)
HDPE[1]	23.17	48	0.70	71.02 (Tested at 4.4 ºC)
PP[2]	37.02	9	1.65	59.18 (Tested at 22.7 ºC)

(1) HDPE samples were manufactured with injection moulding; (2) PP samples were manufactured with compression moulding; (a) Determined according to ASTM D638; (b) Determined according to ASTM D790; (c) Determined according to ASTM D256.

Table 2. Formulations used in high density polyethylene- and polypropylene-wood flour composite (HDPE-WFC and PP-WFC) decking boards.

Ingredients	Concentrations (%)
Polyethylene or polypropylene (ExxonMobil® HDPE HD 6605, ExxonMobil® PP 5262)	44-46
Wood flour (American Fiber)	50
Lubricant (Struktol TPW 113)	4
Coupling agent (Polybond 3200 by Crompton)	0 or 2

and impact properties of the boards were determined. The flexural tests were conducted in accordance with ASTM D 790. The flexural specimens were left at their extruded thickness of 1.9 cm (¾”), and cut to 7.62 by 38.1 cm (3 by 15”). The span length of each specimen was 30.48 cm (12”), with the rest left as overhang. The test fixture used was a four-point bending fixture and the radii of the load points were 0.3175 cm (1/8”), as specified by the standards. Ten samples were tested on the Instron 8801 for each group. The rate of cross-head motion was 8.128 mm/min (0.32 in/min), which is calculated according to the ASTM standard.

The impact tests were conducted according to ASTM D 256. The 1.9 cm (¾”) decking boards were first planed down to 1.27 cm (0.5”) and then ten samples were cut cross-wise from the board using a chop saw. Finally, the notches were added using a NotchVIS machine manufactured by CEAST™ and samples were tested on a Resil 50 B impact test machine, manufactured by CEAST™.

The tensile tests were conducted according to the ASTM D 683. The 1.9 cm (¾”) decking boards were first planed down to 1.27 cm (0.5”) and then ten dog-bone shape samples were cut in the wood shop using a shaper. Tests were conducted using Instron 8801 at a rate of 5.08 mm/min (0.2 in/min). The tensile modulus of the samples was taken as the slope of the curve at stress levels between 0.05% and 0.2%, while the tensile strength is the maximum stress experienced by each specimen.

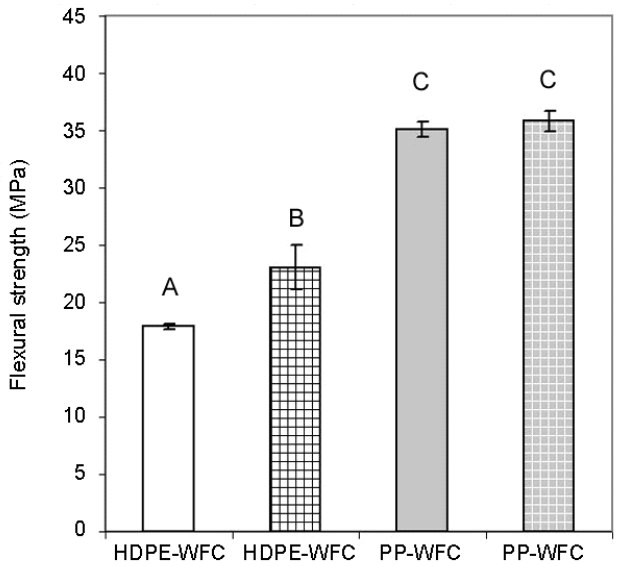

Figure 1. Flexural strength of HDPE-WFC and PP-WFC decking boards. (Bars with the same capital letter are not significantly different).

The two-way ANOVA test was used to analyze the data. Effect of coupling agent and plastic type were investigated. Six material properties were of interest: flexural strength, flexural modulus, impact strength, tensile strength, tensile modulus, and elongation-at-break.

Scanning Electron Microscope

The fractured surface of the samples was also studied using JEOL scanning electron microscope (Model JSM 6400). The samples were first dipped into liquid nitrogen and snapped to half to prepare the fractured surfaces. Then samples were mounted on the sample stub and were sputtered with gold.

RESULTS AND DISCUSSION

Flexural Properties

Table 4 summarizes descriptive statistics of the flexural properties of high density polyethylene-wood flour composite (HDPE-WFC) and polypropylene-wood flour composite (PP-WFC) decking boards. Flexural properties determined were flexural strength and flexural modulus.

Figure 1 shows the flexural strength results of the

Table 3. Extrusion processing parameters during the manufacturing of HDPE-WFC and PP-WFC decking boards.

Extrusion processing parameters			
		HDPE based composites	PP based composites
94 mm parallel counter -rotating twin -screw	Barrel zone 1	96ºC	92ºC
	Barrel zone 2	215ºC	220ºC
	Barrel zone 3	207ºC	215ºC
	Barrel zone 4	202ºC	208ºC
	Barrel zone 5	175ºC	190ºC
	Barrel zone 6	165ºC	175ºC
	Barrel zone 7	155ºC	163ºC
	Barrel zone 8	142ºC	158ºC
	Adapter temperature	160ºC	160ºC
	Melt temperature	151ºC	152ºC
	Die zone 1	185ºC	200ºC
	Die zone 2	185ºC	200ºC
	Die zone 3	185ºC	200ºC
	Die zone 4	185ºC	200ºC
	Screw speed (RPM)	30	30
	Load (%)	24	24
	Pressure (psi)	330	415
75 mm single screw	Barrel zone 1	165ºC	245ºC
	Barrel zone 2	175ºC	235ºC
	Barrel zone 3	180ºC	220ºC
	Barrel zone 4	183ºC	215ºC
	Barrel zone 5	185ºC	210ºC
	Clamp 1 temperature	200ºC	205ºC
	Clamp 2 temperature	200ºC	205ºC
	Adapter temperature	200ºC	205ºC
	Melt temperature	189ºC	195ºC
	Screw speed (RPM)	28	45
	Load (%)	40	31
	Pressure (psi)	1050	1100-1250

HDPE-WFC and PP-WFC decking boards. Bars with different capital letters indicate significantly the different groups. PP-WFC decking boards provided significantly higher flexural strength values compared to HDPE-WFC for all groups (P<0.001). This was expected since the PP resin homopolymer used in this study had much higher flexural properties than HDPE homopolymer (Table 1). The addition of MAPP coupling agent improved the flexural strength of both HDPE-WFC and PP-WFC decking boards. However, this increase was not statistically significant in the case of PP based wood flour composites. Similar increase in flexural strength of HDPE-wood flour composites was also reported by Li et al. [25]. They [25] reported that this increase was more pronounced when PE based maleic anhydride coupling agent was presented in the formulation. For polyolefin-based plastic lumber decking boards, ASTM D 6662 (2001)

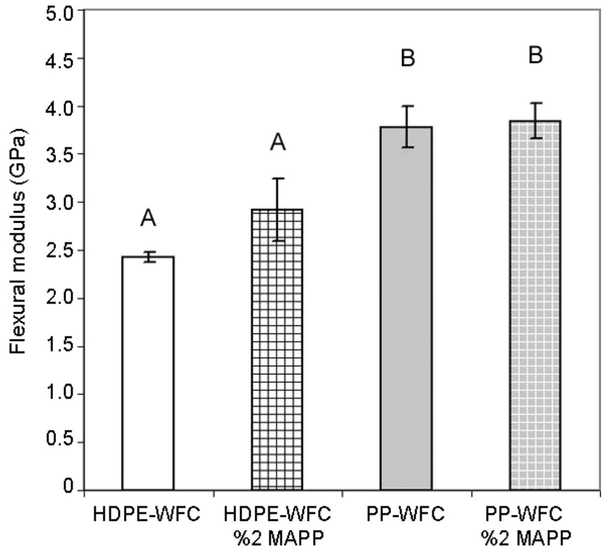

Figure 2. Flexural modulus of HDPE-WFC and PP-WFC decking boards. (Bars with the same capital letter are not significantly different).

Table 4. Descriptive statistics values for flexural testing.

Flexural strength					
Specimen ID	N	Mean (MPa)	Min (MPa)	Max (MPa)	SD
HDPE-WFC	10	17.91	17.20	18.90	0.49
HDPE- WFC + 2% MAPP	10	23.05	16.20	27.00	3.86
PP-WFC	10	35.82	33.30	39.10	1.78
PP- WFC + 2% MAPP	10	35.08	32.50	37.20	1.30
Flexural modulus					
Specimen ID	N	Mean (GPa)	Min (GPa)	Max (GPa)	SD
HDPE-WFC	10	2.43	2.26	2.57	0.10
HDPE- WFC + 2% MAPP	10	2.92	1.80	3.69	0.65
PP-WFC	10	3.84	3.20	4.45	0.37
PP-WFC + 2% MAPP	10	3.79	2.92	4.26	0.43

N: sample size, Min: minimum, Max: maximum, and SD: standard deviation.

standard requires the minimum flexural strength of 6.9 MPa (1,000 psi). All decking boards produced in this study provided flexural strength values (17-35 MPa) that are well over the requirements by the standard.

The flexural modulus of the decking boards is shown in Figure 2. Similar to the flexural strength PP-WFC decking boards provided significantly higher tensile modulus than HDPE-WFC decking boards for all groups ($P<0.001$). Addition of MAPP coupling agent increased the flexural modulus of the boards but this increase was not statistically significant ($P=0.119$). ASTM D 6662 (2001) standard requires the minimum flexural modulus of 0.34 GPa (50,000 psi) for polyolefin-based plastic lumber decking boards. All decking board manufactured in this study provided flexural modulus values (2.4-3.8 GPa) well over required standards.

Impact Properties

Table 5 presents the descriptive statistics of impact properties of WPCs produced in this study. High density polyethylene-wood flour composites (HDPE-WFC) provided significantly higher Izod impact strength compared to polypropylene-wood plastic composites (PP-WFC) for all groups ($P<0.001$). This result might be due to the higher impact strength of HDPE homopolymer compared to the PP homopolymer (Table 1). Izod impact strength of boards with MAPP coupling agent was slightly lower than that of boards without MAPP coupling agent ($P=0.023$). The decrease in impact strength was not unexpected. Mostly reinforced materials are more brittle than their more easily deformable unreinforced counterparts

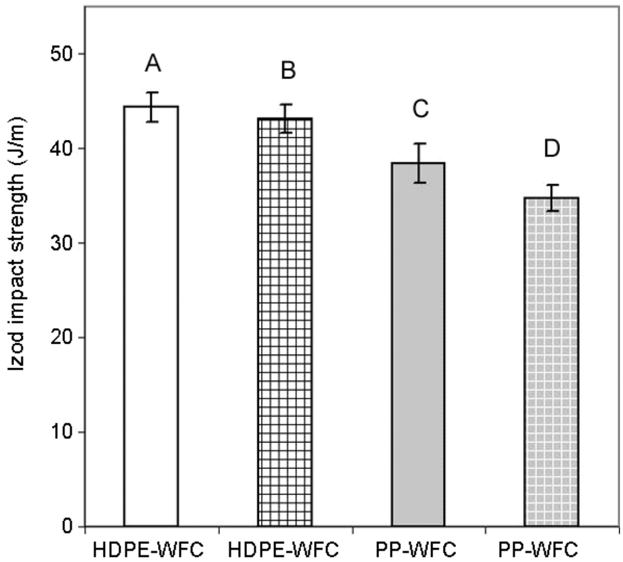

Figure 3. Impact strength of HDPE-WFC and PP-WFC decking boards. (Bars with the same capital letter are not significantly different).

Table 5. Descriptive statistics values for Izod impact testing.

Specimen ID	N	Mean (J/m)	Min (J/m)	Max (J/m)	SD
HDPE-WFC	10	44.38	40.10	49.60	3.11
HDPE- WFC + 2% MAPP	10	43.13	38.90	47.30	2.96
PP--WFC	10	38.43	33.30	46.50	4.14
PP- WFC + 2% MAPP	10	34.74	31.40	40.00	2.84

N: sample size, Min: minimum, Max: maximum, and SD: standard deviation.

[29]. Previous studies showed that increased brittleness of the composite due to enhanced interaction between fibres and polymer can change the mode of failure from "fibre pull-out" to "fibre breakage" while the crack propagates. Lack of intimate adhesion between wood-fibres and plastic causes the fibres to be pulled out and a larger amount of energy is required during crack propagation. On the other hand, when the interface is improved by using MAPP coupling agent, the crack goes through the brittle wood-fibre, and as a result, the overall composite materials become more brittle and the impact strength of the material is reduced [6,7,14].

Tensile Properties

Table 6 summarizes the descriptive statistics of high density polyethylene-wood flour composite (HDPE-WFC) and polypropylene-wood flour composite (PP-WFC) decking boards. Tensile properties determined were tensile strength, tensile modulus, and elongation-at-break.

Figure 4 shows the tensile strengths of HDPE-WFC and PP-WFC decking boards. PP-WFC decking boards provided significantly higher tensile strength values than HDPE-WFC decking boards ($P<0.001$). Tensile strength of both HDPE-WFC and PP-WFC was increased significantly with the use of maleated polypropylene (MAPP) coupling agent ($P<0.001$). However, this increase was more pronounced in the case of HDPE-WFC about 40% compared to PP-WFC which is around 5%. Previous studies [24-27] reported that PP based maleic anhydride

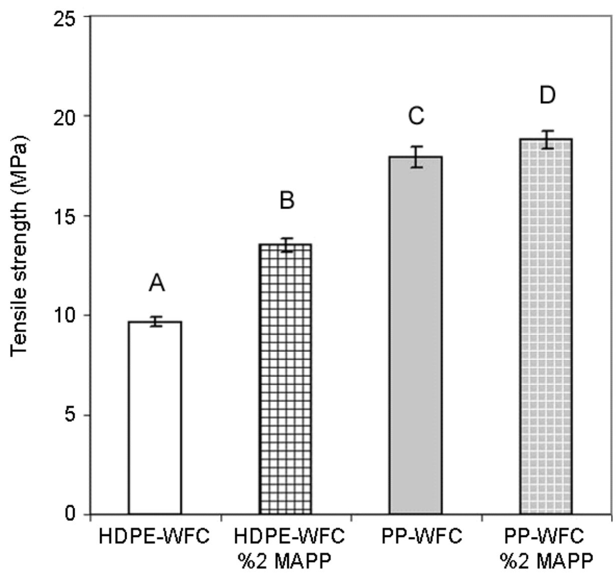

Figure 4. Tensile strength of HDPE-WFC and PP-WFC decking boards. (Bars with the same capital letter are not significantly different).

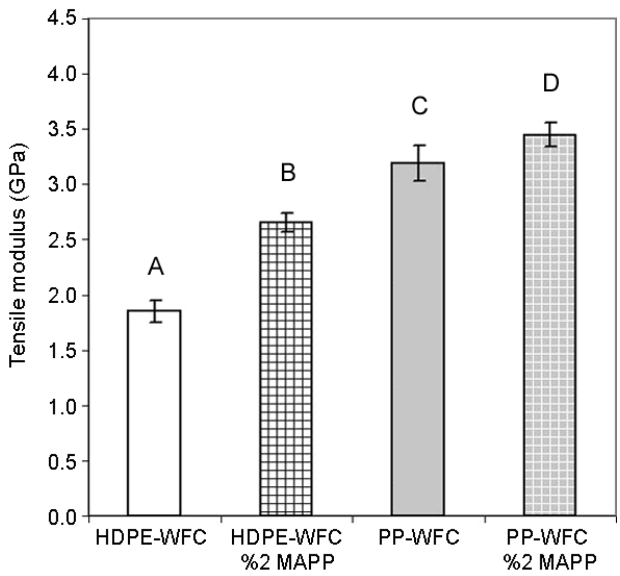

Figure 5. Tensile modulus of HDPE-WFC and PP-WFC decking boards. (Bars with the same capital letter are not significantly different).

Table 6. Descriptive statistics values for tensile testing.

Tensile strength					
Specimen ID	N	Mean (MPa)	Min (MPa)	Max (MPa)	SD
HDPE-WFC	10	9.66	8.90	10.40	0.49
HDPE- WFC + 2% MAPP	10	13.50	12.30	14.40	0.65
PP--WFC	10	17.94	16.60	16.60	1.05
PP- WFC + 2% MAPP	10	18.80	17.30	17.30	0.87
Tensile modulus					
Specimen ID	N	Mean (GPa)	Min (GPa)	Max (GPa)	SD
HDPE-WFC	10	1.85	1.59	1.85	0.20
HDPE- WFC + 2% MAPP	10	2.65	2.39	2.58	0.18
PP--WFC	10	3.19	2.80	3.13	0.32
PP- WFC + 2% MAPP	10	3.45	2.97	3.48	0.22
Elongation-at-break					
Specimen ID	N	Mean (%)	Min (%)	Max (%)	SD
HDPE-WFC	10	2.89	2.20	3.73	0.45
HDPE- WFC + 2% MAPP	10	2.11	1.50	2.50	0.31
PP--WFC	10	2.40	1.74	2.87	0.41
PP- WFC + 2% MAPP	10	1.76	1.30	2.19	0.28

N: sample size, Min: minimum, Max: maximum, and SD: standard deviation.

(MAPP) is not a suitable coupling agent for HDPE based composites due to the better wetting of the PE based maleic anhydride (MAPE) to the HDPE matrix polymer. In the present study, MAPP coupling agent has performed satisfactorily for HDPE-based WPC decking boards. It is believed that this difference was caused by HDPE based resin used in this study. HDPE was narrow molecular weight hexene copolymer. Yamaguchi et al. [28] reported that polypropylene is miscible in the amorphous region of the polyethylene-hexene copolymers. Probably, this helped the maleated polypropylene to perform better as a coupling agent in a polyethylene based WPCs. It should also be noted that even with this significant increase with the use of MAPP coupling agent, HDPE-WFC still has lower tensile strength than PP based wood flour composites.

In the case of tensile modulus, similar trends were observed (Figure 5). PP-WFC decking boards provided significantly higher tensile modulus than HDPE-WFC decking boards ($P<0.001$). Addition of MAPP coupling agent significantly increased the tensile modulus of both HDPE-WFC and PP-WFC decking boards due to the better adhesion between plastic and wood flour and the reinforcing effect of wood flours ($P<0.001$) [17,30]. Once again this increase was more evident in HDPE-WFC compared to PP-WFC decking boards. It should also be noted that PP based com-

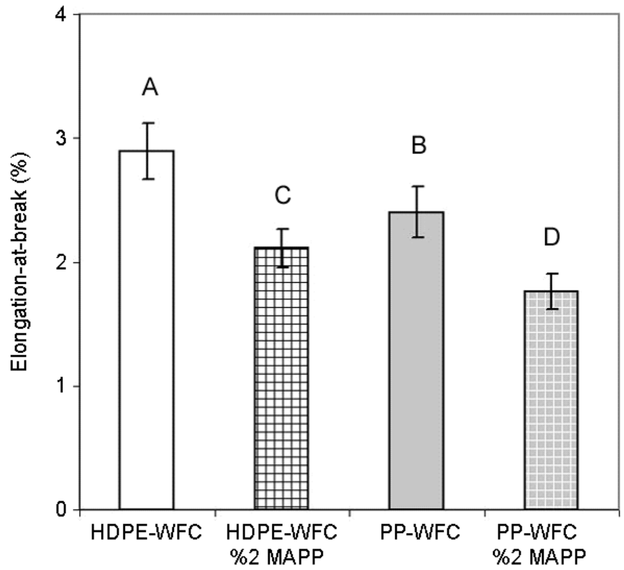

Figure 6. Elongation-at-break of the HDPE-WFC and PP-WFC decking boards. (Bars with the same capital letter are not significantly different).

posite without MAPP coupling agent still had significantly higher tensile modulus than HDPE-WFC with coupling agent.

In the case of elongation-at-break, HDPE based wood flour composites had slightly higher results than PP based wood flour composites (Figure 6). This result was expected because HDPE matrix has higher elongation-at-break values (48%) compared to PP matrix (10%). It is well known that when wood flour was incorporated to the plastic matrix, resulted composites become more brittle and produce lower elongation-at-break values. Similar results were reported in other studies [1,6,7,14,17,18,30]. Addition of MAPP coupling agent significantly reduced the elongation-at-break of both HDPE-WFC and PP-WFC decking boards ($P<0.001$). It is believed that the use of coupling agent created a strong cohesive interaction between wood flours and plastic. This has resulted in an increase on the brittleness of composites and reduced the elongation-at-break values. Usually in composites, lower elongation-at-break values were observed with increased modulus [6,7].

Morphology

Figures 7a-7d show the SEM micrographs of fractured surface of the decking boards. Figures 7a and 7c present the unmodified (no MAPP) HDPE-WFC and PP-WFC, respectively. The arrows show the individual fibres presented in the matrix. This result was due to the poor adhesion between not compatible wood flours (hydrophilic) and plastic matrix (hydrophobic). Figures 7b and 7d present HDPE-WFC and PP-WFC modified with 2% MAPP coupling agent, respectively.

It can be observed that some wood flour was embedded into the plastic matrix showing good adhesion. However, the bonding is not perfect because some debonding can also be observed on the inter-

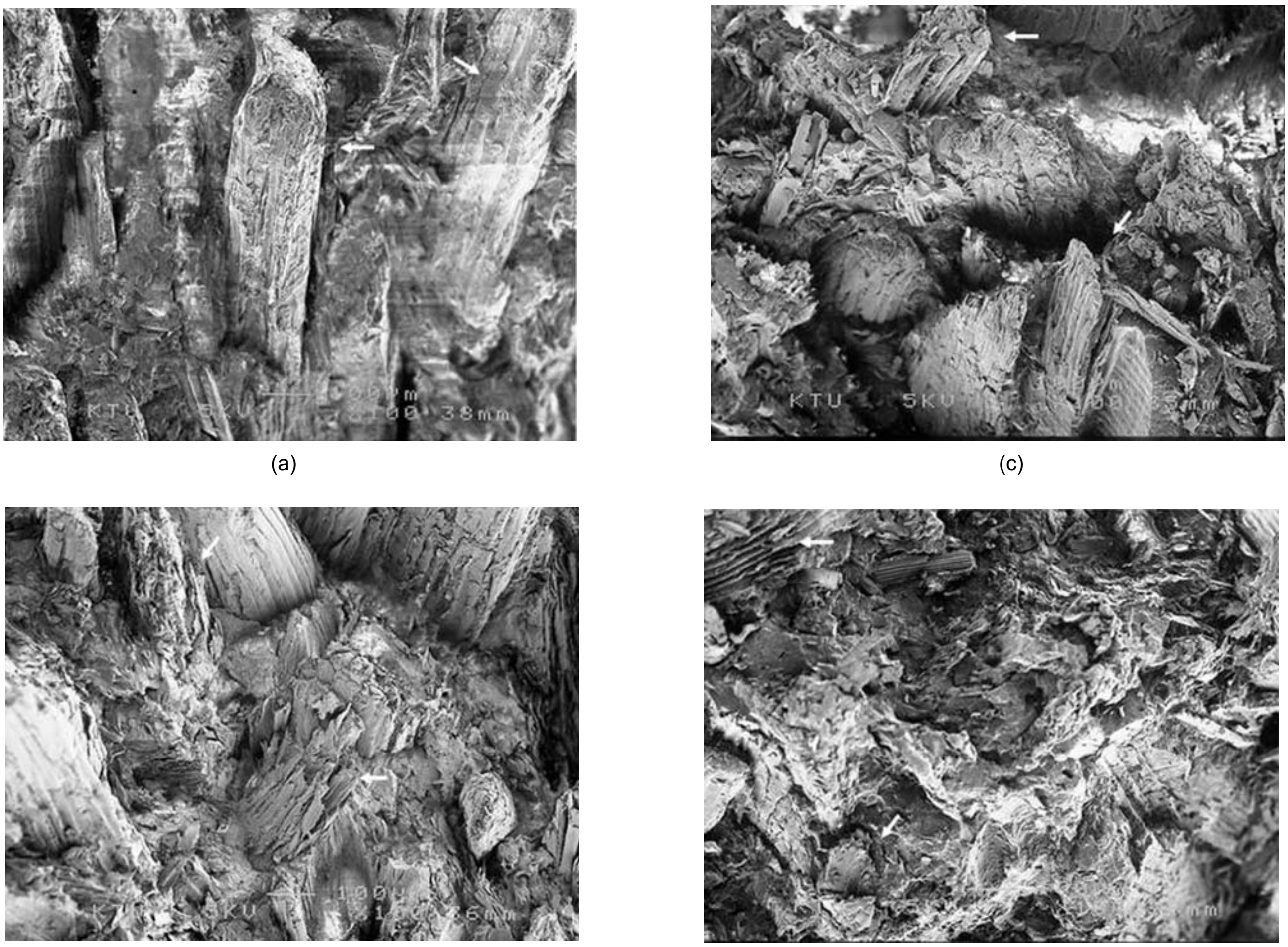

Figure 7. SEM Micrographs of: (a) HDPE-WFC, (b) HDPE-WFC + 2% MAPP, (c) PP-WFC, and (d) PP-WFC + 2% MAPP.

face of wood flour and plastic matrix.

CONCLUSION

This study determined the selected mechanical properties of commercial size HDPE copolymer- and PP homopolymer-wood flour composite decking boards. Effect of maleated polypropylene as a coupling agent was quantified. Flexural, tensile and impact properties of the decking boards were evaluated. Results showed that PP-WFC decking boards outperformed HDPE-WFC decking boards in flexural and tensile properties. It should also be noted that with the use of MAPP coupling agent, tensile strength and tensile modulus were increased significantly for both HDPE-WFC and PP-WFC composite decking boards. MAPP coupling agent slightly increased the flexural strength of HDPE-WFC but did not affect the flexural modulus. Contrary to the previous studies, this study showed that MAPP coupling agent can effectively be used as a coupling agent for HDPE based resin. It is believed that this performance was due to the base resin used in this study since it was narrow molecular weight hexene copolymer HDPE. In the case of PP-WFC composites, addition of MAPP coupling agent had no significant affect on flexural strength and flexural modulus. It should also be noted that addition of MAPP coupling agent significantly reduced the notched Izod impact strength of the decking boards. Morphological study also showed the effect of MAPP coupling agent on the compatibility of wood flour and plastic matrix. In conclusion, both HDPE-WFC and PP-WFC decking boards provided good mechanical properties. For polyolefin-based plastic lumber decking boards, ASTM D 6662 (2001) standard requires the minimum flexural strength of 6.9 MPa (1,000 psi) and flexural modulus of 0.34 GPa (50,000 psi), which were easily achieved by all groups.

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