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PHYSICAL AND BENDING PROPERTIES OF INJECTION MOULDED WOOD PLASTIC COMPOSITES BOARDS

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ABSTRACT

There is increasing number of companies producing wood-plastic composite for structural applications. However, wood plastic composite (WPC) require solving two major constraints; technique and formulation before their design value for structural application can be determined. This study focused on solving the two major constraints by employed injection moulding method to produce WPC and using different commercial available coupling agents at different percentage to produce WPC. The effect of wood to plastic ratio was also evaluated on WPC produced using the coupling agents that gave highest bending properties. Commercial polypropylene wood fine and coupling agents premixed in dumper mixer for 30 minutes prior to extrusion process at temperature of 190^{o}C using 110 mm counter-rotating twin-screw extruder. The WPC boards with size of 150 mm x 150 mm x 3 mm were then injection moulded by 40-ton press moulding machine. From the result, WPC produced from coupling agents Exxelor PO 1020 at 4% significantly performed better in bending properties. Further study on the effect of Exxelor PO 1020 percentage and the wood to plastic ratio showed that, WPC with 65% wood fine performed significantly better in MOR and MOE than other type of WPCs. WPC with 60% wood fine had significantly lower thickness swelling and water absorption compared to those 65% and 70% wood fine WPC. Conclusively, WPC with 65% wood fine is optimum content for WPC to produce from injection moulded method. Higher coupling agent percentage used in WPC formulation gave higher bending properties.

Keywords: wood plastic composite, coupling agents, bending, physical, properties.

INTRODUCTION

Over the past decade, there has been a growing interest in the development of construction and industrial products composed of wood fiber combined with thermoplastic resins. This mainly due to wood plastic composites (WPC) are renewable, less-abrasive to processing equipment, environmental friendly, low maintenance and similar as wood feature. The use of wood waste as filler make WPC promoted as environmental friendly products.

WPC and WPC process was patented in Italy around 1920s. In this process, polypropylene and wood flour were extruded to manufacture automotive interior parts. There was not much of an interest on this process until one American company implementing this Italian extrusion technology to produce automotive interior substrates (Clemons, 2002). This has followed by other companies to produce various shapes of automotive parts by extruding polypropylene and wood flour mixtures. Applications for these composites include a variety of building products, consumer, industrial and automotive. Recently, WPCs have found application areas other than automotive industry such as siding, fencing, window frames and decking. 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 (Winandy, 2004).

As the use of wood-plastic composite (WPC) materials extends to include more structural applications, there is an increasing need to determine design values appropriate for designing structural WPC elements. However, there are two important topics shall be clearly identify as basic approach toward WPC design value determination. The first issue shall been looking on the WPC processing method and the second issue will be specific formulation which to optimize the WPC mechanical properties to suit the general structuring application. In the first case, injection moulded method had been used for this study due to it provide higher mechanical value and reducing cellulose degradation that normally due to prolong of high temperature exposure. Then, by employ different coupling agents at certain percentages on WPC formulation, the mechanical properties of WPC can be predicted.

Many studies noted that maleic anhydride grafted synthetic polymer when used as compatibilizer, have proven to be having a bridging effect between wood filler and the polymer matrix, resulting in improvement of material mechanical properties (Lu *et al.*, 2000; Sanadi *et al.*, 1997). However, the molecular weight and amount of MA grafted are important parameters that determine the efficiency of the additive (Felix *et al.*, 1993; Sanadi *et al.*, 1995). The maleic anhydride present in the MAPP provides polar interactions such as acid-base interactions and can also covalently link to the hydroxyl groups on the lignocellulosic fiber. However, not all commercial coupling agents give the same effect on WPC performance. Some commercial coupling agents might contain other compound such as flow agent element. This element able to improve the WPC flow characteristic but the higher of this element will affect the poor performance in bending strength. Therefore, the selection of coupling agent is very important to suit to the WPC product application and processing methods requirement. Therefore, this study has two main objectives; the first objective was to evaluate the effect of different industry coupling agents on the bending properties of WPC. Whereas, second objective was to determine the effect of wood to plastic ratio on the physical and bending properties of WPC produced from industry coupling agent that gave the highest bending properties resulted from the first objective.

MATERIALS AND METHODS

Experimental design

This study was separated into two experiments; the first experiment focused on evaluating the effect of different industry coupling agents on the bending properties of WPC. Whereas, second experiment focused on evaluate the effect of wood to plastic ratio on the physical and bending properties of WPC produced from industry coupling agent that gave the highest bending properties resulted from the first experiment.

For the first experiment, commercial polypropylene (PP) Homopolymer G452 with melt index of 45g/10min used in this study was supplied from PROPELINAS, Malaysia. Wood wastes obtained from the industries were hammer to 40 mesh of size to use as wood filler. Three types of Maleic anhydride base coupling agent, Exxelor PO 1020 with melt flow index of 119 g/10min (190^{0}C and 1.2kg) from ExxonMobil Chemical, CA10512 with melt flow index of 10 g/10min (190^{0}C and 0.325kg) from TLK Polytech and low molecular weight emulsion type Epolene E-43 from Westlake Chemical were chosen for this study. Table-1 shows the formulations used for the wood plastic composite in this study.

Table-1. Formulations used in making wood plastic composites.

Panel type	Mixture formulations (%)			Type of coupling agent
	Wood fiber	Plastic (PP)	Coupling agent	
65/33/2PO	65	33	2	Exxelor PO 1020
65/31/4PO	65	31	4	Exxelor PO 1020
65/33/2CA	65	33	2	CA 10512
65/31/4CA	65	31	4	CA 10512
65/33/2EP	65	33	2	Epolene E-43
65/31/4EP	65	31	4	Epolene E-43

For the second experiment of this study, WPC with 30%, 35% and 40% of PP at different MAPP concentrations (1%, 2%, 3% and 4%) were prepared. Table-2 shows the formulations used to study the effect of wood to plastic ratio and MAPP percentages on the bending performance of WPC.

Table-2. Formulations used in making different wood to plastic ratio WPC.

Panel type	Wood fine (%)	PP (%)	MAPP (%)
60/39/01	60	39	1
60/38/02	60	38	2
60/37/03	60	37	3
60/36/04	60	36	4
65/34/01	65	34	1
65/33/02	65	33	2
65/32/03	65	32	3
65/31/04	65	31	4
70/29/01	70	29	1
70/28/02	70	28	2
70/27/03	70	27	3
70/26/04	70	26	4

WPC Processing

Wood fines with 40 mesh size were dried at temperature 120°C to moisture content 0.5% using drying screw conveyor. All compound premixed in dumper mixer for 30 minutes prior to extrusion process at temperature of 190°C using 110 mm counter-rotating twin-screw extruder made by Daechang Machinery Ind. Co. Ltd. The WPC boards with size of 150 mm x 150 mm x 3 mm were then injection moulded by 40-ton press moulding machine. The temperature of the mould was set at 120°C. The WPC boards were conditioned in conditioning room at 25°C with relative humidity of 65±5%.

Evaluation

Samples were cut into the required sizes and shapes in accordance with the standard procedures. Test procedures of static bending, tensile water absorption, and thickness swelling after a 2-h and 24-h water soak were conducted. All tests were determined according to the ASTM D 1037-99. High magnification micrographs on the microcellular structure of WPC produced were examined with scanning electron microscope (SEM).

RESULTS AND DISCUSSIONS

Moisture content and specific gravity

The moisture content (MC) of all the WPC board produced were range from 1-2%. The average specific gravity of all samples was about 1.15. Table-3 shows the moisture content and specific gravity for the WPC boards produced in first experiment, whereas, Table-4 shows the moisture content and specific gravity for the WPC boards produced in second experiment.

Table-3. Moisture content and specific gravity of WPC produced from different industry coupling agents.

Type of WPC	Moisture content (%)	Specific gravity
65/33/2PO	0.8	1.21
65/31/4PO	0.9	1.13
65/33/2C	0.6	1.20
65/31/4C	0.7	1.14
65/33/2E	0.9	1.16
65/31/4E	0.8	1.13

Table-4. Moisture content and specific gravity of WPC produced from different wood plastic ratio.

Type of WPC	Moisture content (%)	Specific gravity
60:39:01	0.8	1.11
60:38:02	0.7	1.18
60:37:03	0.5	1.13
60:36:04	0.7	1.11
65:34:01	0.9	1.12
65:33:02	0.8	1.21
65:32:03	0.8	1.13
65:31:04	0.9	1.13
70:29:01	1.4	1.16
70:28:02	0.9	1.22
70:27:03	2.1	1.14
70:26:04	1.5	1.14

Bending properties

Table-5 shows the average values of each designative combination of treatments of board bending properties for WPC board produced in first experiment. As shown in the table, the WPC board produced using Exxelor PO 1020 as coupling agent at 4% had significantly higher MOR and MOE values compared to other WPC boards. Therefore, Exxelor PO 1020 was selected as coupling agent for second experiment.

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Table-5. Bending properties of wood plastic composites.

Type	Static bending (MPa) MOR	MOE
65/33/2PO	20.40^{c}	2131^{d}
65/33/2C	25.37^{b}	2494^{c}
65/33/2E	21.54^{c}	2804^{b}
65/31/4PO	63.35^{a}	4279^{a}
65/31/4C	25.85^{b}	2749^{bc}
65/31/4E	21.35^{c}	2884^{b}

All the data are based on average value from 10 specimens.
Mean with the same letter is not significantly different at 95% level of confidence.

Table-6 presents results of the second experiment in this study. An two-way ANOVA was performed to determine which experimental factors; wood to plastic ratio, MAPP percentage and their interactions were of significant influence on the bending properties. The ANOVA indicated that there was interaction between the wood to plastic ratio and MAPP percentage at 95% level of confidence.

Table-6. Statistical analysis result for the effect of wood to plastic ratio and MAPP percentage.

Wood fine loading (%)	MAPP (%)	Flexural Strength (MPa) DMOR	WMOR	DMOE	WMOE
60	1	23.2^{cd}	21.4^{cde}	1899^{d}	1504^{ef}
	2	23.7^{cd}	21.9^{cde}	2094^{cd}	1663^{de}
	3	24.6^{cd}	25.1^{c}	2278^{bc}	1985^{cd}
	4	26.2^{c}	24.3^{cd}	2560^{b}	2266^{c}
65	1	22.0^{cd}	18.2^{e}	2115^{cd}	1252^{f}
	2	20.4^{d}	19.5^{de}	2131^{cd}	1538^{ef}
	3	25.6^{cd}	24.6^{cd}	2568^{b}	2161^{c}
	4	63.4^{a}	58.0^{a}	4276^{a}	3516^{a}
70	1	22.4^{cd}	18.7^{e}	2349^{bc}	1350^{ef}
	2	21.3^{cd}	20.5^{cde}	2224^{bcd}	1528^{ef}
	3	22.7^{cd}	18.9^{e}	2520^{b}	1486^{ef}
	4	42.2^{b}	38.5^{b}	4241^{a}	3086^{b}

Mean with the same letter is not significantly different at 95% level of confidence.

As shown in the Tables, the WPC boards made from 65% wood fine 31% PP and 4% MAPP had significantly higher MOR and MOE values compared to other WPC boards. Woodhams *et al.* (1984) revealed that critical wood fine content is required before reinforcement may be attained. Beyond that loading, PP composites give low values because the blend is too viscous to mould properly. This may explain why WPC produced from 65% wood fine performed significantly better than those 60% and 75% wood fines.

All the WPC boards produced in this study using 4% MAPP gave higher MOR and MOE values compared to those WPC using 3%, 2% and 1% MAPP. This finding may indicate that when 4% MAPP was added, the wood-plastic interaction of the composites improved. The above statement supported by SEM results of the WPC microcellular structure shown in Figure-1(a) and (b). As shown in Figure-1(a), it's clearly indicates the poor interfacial adhesion between wood fiber and PP, thus revealing the low affinity between the polymer matrix and the wood fiber. However, by increase the coupling agent

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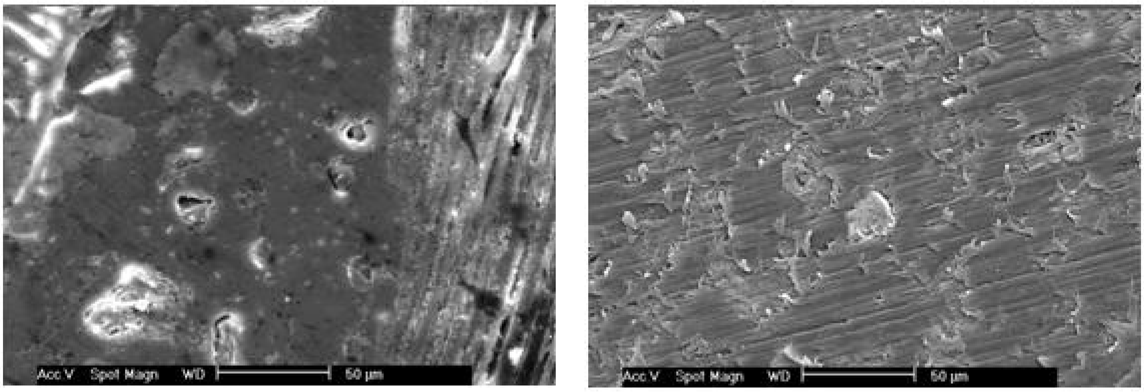
contains to 4% as shown in Figure-1(b), it produced a more homogeneous surface with less voids and cavities. Better encapsulation of PP on the wood fine was found in the WPC boards produced from 4% MAPP. Myers *et al.* (1991) and Olsen (1991) also reported that higher percentage of MAPP used in WPC formulation caused big improvements in the flexural strength of wood flour/PP composites.



(a) **(b)**

Figure-1. SEM micrograph of WPC board with (a) 2% MAPP and (b) 4% MAPP.

Water absorption and thickness swelling

The result of water absorption for 2-hour and 24-hour water soaking test presented in Table-7. All the WPC boards had very low percentage of water absorption after 2-hour and 24-hour water soaking tests. An interaction between the wood fine loading and MAPP percentage was observed from the two-way ANOVA performed on the water absorption data. WPC board produced with 70% wood fine had significantly higher water absorption than those WPC with 60% and 65% wood fine at 2-hour and 24-hour water soaking tests. According to Stark (2001), less encapsulation occurs with WPC having higher wood fine content, wood easily expose on the surface of the WPC. Therefore, higher amount of water absorption observed in those WPC. Beside that, All the WPC produced using 4% MAPP slightly lower in water absorption compared to 1%, 2% and 3% MAPP used.

Table-7. Statistical analysis results on water absorption for the effect of wood to plastic ratio and MAPP percentage.

Wood fine loading (%)	**MAPP** (%)	**Water absorption** (%)	
		2 hour-water soak	24 hour-water soak
60	1	0.51^{def}	2.03^{ef}
	2	0.47^{def}	1.48^{fg}
	3	0.17^{g}	0.84^{g}
	4	$0..27^{fg}$	1.06^{g}
65	1	1.02^{bc}	4.14^{b}
	2	0.65^{de}	2.32^{de}
	3	0.55^{def}	2.13^{ef}
	4	0.25^{fg}	1.18^{g}
70	1	1.60^{a}	5.27^{a}
	2	0.75^{cd}	2.97^{cd}
	3	1.32^{ab}	3.67^{bc}
	4	0.44^{efg}	2.46^{de}

Mean with the same letter is not significantly different at 95% level of confidence.

Figure-8 shows the statistical result of thickness swelling for the effect of wood to plastic ratio and MAPP percentage. From the statistically analysis, The WPC with 70% wood fine had significantly higher in thickness swelling compared to other type WPC with the value range of 2.43%-5.00% and 1.07%-1.81% for 24-hour and 2-hour water soaking test, respectively. The MAPP percentage was no significant affect the thickness swelling of WPC especially for 2-hour water soaking test.

Table-8. Statistical analysis results on thickness swelling for the effect of wood to plastic ratio and MAPP percentage.

Wood fine loading (%)	**MAPP** (%)	**Thickness swelling** (%)	
		2 hour-water soak	24 hour-water soak
60	1	0.97[cd]	2.65[bc]
	2	0.66[cd]	1.93[c]
	3	0.64[cd]	1.82[c]
	4	1.11[bc]	2.17[c]
65	1	1.06[c]	3.59[b]
	2	0.92[cd]	1.89[c]
	3	0.96[cd]	2.85[bc]
	4	0.42[d]	1.73[c]
70	1	1.66[ab]	4.86[a]
	2	1.07[c]	2.43[bc]
	3	1.81[a]	5.00[a]
	4	1.15[bc]	2.88[bc]

Mean with the same letter is not significantly different at 95% level of confidence

CONCLUSIONS

Conclusively, WPC produced from coupling agents Exxelor PO 1020 at 4% gave best bending performances. Beside that, 65% wood fine gave the optimum content in WPC formulation. Above this level, the blend is too viscous to flow using injection moulding method to produce WPC boards. Higher percentage of coupling agent used in WPC boards will provide higher bending properties and lower water absorption but not in thickness swelling.

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