Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 11 (2): 384-388, 2011
ISSN 1812-5654 / DOI: 10.3923/jas.2011.384.388

Biological Durability of Injection Moulded Wood Plastic Composite Boards

[1]P.S. H'ng, [1]A.N. Lee, [1]C.M. Hang, [1]S.H. Lee, [2]A. Khalina and [2]M.T. Paridah
[1]Faculty of Forestry, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia
[2]Laboratory of Biocomposite Technology, Institute of Tropical Forestry and Forest Products, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia

Abstract: The steadily growth of Wood Plastic Composite (WPC) in exterior applications resulted a need to understand their durability. In Malaysia, the durability of WPC is not only affected by mold and decay fungi as biodegradation agents but also due the termites attack. Therefore, this study was carried out to investigate the durability of WPC produced from different wood fine loadings (60, 65 and 70%) and MAPP (1, 2, 3 and 4%) concentration. The aim of this study is to determine the optimum WPC formulation associate with higher durability against biodegradation agents. Commercial polypropylene, wood fines and coupling agent premixed in dumper mixer for 30 min prior to extrusion process at temperature of 190°C using 110 mm counter-rotating twin-screw extruder. The premixed raw materials were then subjected to injection moulded using 40 ton press moulding machine and pressed into size of 30 mm×30 mm and 3 mm thick board. Biological durability tests were carried out according to ASTM D4445 for mold, ASTM method D 2017 for decay fungi and ASTM D 3345 for termites. From the result, 70% wood fine loading showed significantly lower durability due to the insufficient encapsulation of wood fine with polymer matrix. Higher percentage of coupling agent (MAPP) used in the WPC boards will provide higher durability of WPC. Conclusively, the optimum formulation for WPC i.e., 4% MAPP and 60% wood fine loading gave the highest protection against mold, decay fungi and termites.

Key words: Wood plastic composite, wood fine loading, termites, mold, decay fungi

INTRODUCTION

The demand for Wood Plastic Composites (WPC) is increasing despite the present world's economic slowdown. Currently, more than 1.5 million tons of WPC are produced worldwide where North-America accounted about 1 million tons of production, followed by China (200,000 tons) and Japan (100,000 tons) (Liu, 2009). Germany is the European leader with more than 70,000 tons. The main areas for the application of WPC are in the automotive industry for car interiors and also in decking's (Eder, 2009). Decking's are floor coverings, used mainly in outdoor areas, such as terraces and public places. These decking's are increasingly becoming an alternative to tropical timber and sales volume shows a yearly double digit growth. The freedonia group's wood and competitive decking report (issued in April 2009), demand for WPC decking is expected to rise 9.5% year^{-1} during that period to as high as 700 million lineal feet year^{-1} (213.6 million m year^{-1}) (Anonymous, 2009).

Almost, all the WPC products originally were marketed as maintenance free and were given warranties range from 10 to 25 years on up to limited lifetime. Protection against decay and rot is typically mentioned in the most warranties. Nonetheless, recent WPC conferences and papers highlighted durability of the WPC against biological agents (Kamdem *et al*., 2004; Morrell *et al*., 2006). Initially, it was assumed that thermoplastic material completely encapsulated the wood component of the composite, providing protection against water absorption and therefore against biological and water damage. Nonetheless, Kamdem *et al*. (2004), Pilarski and Matuana (2006) and Morris and Cooper (1998) found fungal growth on wood plastic composite in laboratory and field tests. They stated that this may due to the fact that water absorption on the WPC surface is the key parameter as this is where the biological attack can start. Normally, if the moisture content of the WPC surfaces less than 25%, it is too low to initiate decay and fungus growth. However, laboratory measurements of moisture absorption demonstrate the threshold 25% Moisture Content (MC) level for fungus to grow can be achieved (Kim *et al*., 2008).

As mentioned early, the durability of these materials in exterior environments is just beginning to be understood. Nevertheless, Wood-Plastic Composites (WPCs) have been gaining market share in the residential construction industry. Therefore, several specification and standard being drafted and placed into the market for reducing the effect of durability of WPC on the structures

Corresponding Author: P.S. H'ng, Faculty of Forestry, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia

of construction materials. Model building codes (ICC-ES) are looking at durability evaluation as part of acceptance criteria development. Standards setting organizations in Europe (CEN TC 249 WG 13) and North America (AWPA) are developing specific standard for WPC durability.

Many studies were being carried out in order to improve the durability of the WPC (Mitsuhashi and Morrell, 2010; Kim *et al*., 2008; Morrell *et al*., 2006). Current research suggested that controlling moisture absorption by the composite was the key to improving durability. In this study, the injection moulded process was used to improve the moisture resistance and in this manner, the durability of WPC. Nonetheless, the decay of WPC's depends not only on the process but also the formulation. Polymers and bio-fibers each have their own separate degradation mechanisms. The WPC board with different wood and plastic polymer might have different degradation that need to be understood.

Therefore, this study was carried out to investigate the biological durability of WPC produced from different wood fine loadings (60, 65 and 70%) and MAPP (1, 2, 3 and 4%) concentration. The aim of this study is to determine the optimum WPC formulation associate with higher durability against biodegradation agents.

MATERIALS AND METHODS

This project was carried out from year 2006 to 2009. Commercial Polypropylene (PP) Homopolymer (PROPELINAS) G452 with density and melt index of 0.9 g cm^{-3} and 45 g/10 min, respectively was supplied by Polypropylene Malaysia Sdn. Bhd., Malaysia. Rubberwood in the form of waste was obtained from the commercial furniture factory. Coupling agent; maleic anhydride (MAPP) Exxelor PO 1020 with melt flow index of 119 g/10 min was obtained from ExxonMobil Chemical, Malaysia.

The rubberwood waste obtained from the furniture factory was hammered into 40 mesh size for use as wood filler in WPC. The wood fines were dried to less than 1% moisture content prior to the compounding process. During the compounding process, wood fine was premixed with PP and MAPP in dumper mixer for 30 min before subjected to 110 mm counter-rotating twin-screw extruder made by Daechang Machinery Ind. Co. Ltd., at temperature of 190°C. The pellets from the compounding process were then injection moulded by 40 ton press moulding machine formed into 3 mm thick board. The process was repeated for making WPC board with different formulations. The formulations for different WPC boards are summarized in Table 1. Each of the WPC formulation produced 10 boards and total of 120 boards were produced in the study. The percentage of MAPP (1, 2, 3 and 4%) was calculated based on the weight of PP. The weight of the rubberwood fine loading (60, 65 and 70%) of the total formulation was kept constant while the ration of PP and MAPP was varied. After the pressing, all the samples were conditioned in conditioning room maintained at relative humidity of 65±5% and 25±20°C until the moisture content of the samples reached an equilibrium moisture level.

Table 1: Formulation for WPC board

Treatment	Wood (%)	PP (%)	MAPP (%)
60:39:1	60	39	1
60:38:2	60	38	2
60:37:3	60	37	3
60:36:4	60	36	4
65:34:1	65	34	1
65:33:2	65	33	2
65:32:3	65	32	3
65:31:4	65	31	4
70:29:1	70	29	1
70:28:2	70	28	2
70:27:3	70	27	3
70:26:4	70	26	4

The Moisture Content (MC) of WPC board was determined by oven-dried method. The samples were oven-dried at 103±2% to a constant weight. The less in weight was expressed as a percentage of the final oven-dried weight and take as the moisture content of the test samples. Density of WPC board was determined by weight of WPC at 1% MC over the dimension (length, width and thickness).

The biological durability of WPC boards produced were evaluated against mold, decay fungi and subterranean termite. Sixty pieces of WPC samples with size of 20 mm in width, 70 mm in length and 3 mm thick were prepared for molds test. Whereas, sixty pieces of WPC samples with the size of 25 mm in width, 25 mm in length and 3 mm in thick were prepared for decay fungi and termites tests, respectively. Each formulation was tested on the biological durability based on five replicates.

Mold resistance test was carried out according to ASTM D 4445 standard: standard test method for fungicides for Controlling Sapstain and Mold on Unseasoned lumber (laboratory method) using *Penicillium* sp. (ASTM, 2003). The WPC test specimen was placed on a U-shaped glass rod (3 mm in diameter). The glass rod was placed on top of the wet papers inside the sterilized Petri dish. Mold (*Penicillium* sp.) was applied onto the wet paper and the petri dish was seal with cellophane tape to prevent any contaminant with the contact of surrounding atmosphere and incubated for 4 weeks in incubator at 27°C and 70% RH. At the end of the testing (after 4 weeks), the number of days for the mold to be visually observed (start to grow) on the test block and coverage area by mold on test block were recorded.

Decay resistance of WPC boards was tested according to ASTM method D 2017-71: Reapproved 1978 using cultures of common white rot fungus *Pycnoporous sanguineus* (ASTM, 1978) and loam soil to provide substrate for the fungus. *Pycnoporous sanguineus* was use due to its commonly found in household area in the country. The pine wood feeder strips were prepared and cut into dimensions 3 mm×28 mm×34 mm with the grain of the wood parallel to the long dimensions and with the edge grain exposed to the flat face. Five replicate of each formulation was test for the decay fungi test. Malt agar substrate was used as the nutrient medium for Petri dish cultures of fungi. The culture media was sterilized at 121°C (250°F) for 20 min and was cooled before inoculations.

A volume of 118cm^{3}of sieved oven-dry soil and 130% water holding capacity, a substrate for the fungus were half-filled the 8 oz culture bottles. Forty six grams of reagent water was added and then the feeder strips was placed directly on the soil of each culture bottles. The prepared bottles were sterilized with caps loosen at 121°C for 20 min. The conditioned and weighed test samples were tight closely in a container and steamed at 100±2°C for 20 min.

After 8 weeks of incubation at 27°C and 70% RH, the surface fungus mycelium was removed, the specimens weight loss were calculate when the samples were dried at 60°C after 1 week interval, as percentage of total WPC test block mass.

Termite resistance of WPC boards was tested according to ASTM D3345-74 standard using the subterranean termite, *Coptotermes curvignathus* (ASTM, 1980). WPC test samples were placed in the center of a cylindrical plastic container (50 mm in diameter and 38 mm in height) with 1 g of subterranean termites together with the control test samples. The containers were maintained at 25°C and 80% RH for 4 weeks. Termite activity in each bottle was observed and rated after 1 and 4 week of the testing period. At the end of the testing period, the percentages of weight loss due to termite attack and termites mortality rate were calculated.

At the end of the test, all the data collected were statistically analyzed using Analysis of Variance (ANOVA) to verify the significance of the variables studied. Mean Separation was carried out using Least Significant Difference (LSD) to further analyze the effect of the variables studied.

RESULTS AND DISCUSSION

Moisture content and density: Table 2 showed the Moisture Content (MC) and density of the WPC board produced, the moisture content of the WPC boards was range from 1 to 3%. The average density of the WPC boards was about 1.16 g cm^{-3}.

Durability against molds: The mold durability test involved two properties, i.e., number of days of molds start to grow (molds first appear on the WPC boards) and mold coverage area on WPC after exposed to the *Penicillium* sp. As shown in Table 3, WPC board produced with 60% wood fine found to be mold resistant

Table 2: Moisture content and density of WPC produced from different wood fine loading and MAPP percentage

Treatments	Moisture content (%)	Density (g cm^{-3})
60:39:1	1.28	1.14
60:38:2	1.58	1.20
60:37:3	0.87	1.14
60:36:4	1.44	1.12
65:34:1	0.45	1.15
65:33:2	2.19	1.22
65:32:3	0.47	1.13
65:31:4	1.53	1.14
70:29:1	1.66	1.16
70:28:2	2.65	1.23
70:27:3	1.72	1.17
70:26:4	2.99	1.14

Table 3: Durability of WPC boards against mold

		Mold coverage area (%)			
Treatments	Days for mold to appear	Week 1	Week 2	Week 3	Week 4
60:39:1	6	7 (1)	14 (2)	20 (2)	25 (2)
60:38:2	6	3 (1)	5 (1)	7 (1)	9 (1)
60:37:3	6	4 (1)	5 (1)	7 (1)	9 (1)
60:36:4	7	0 (0)	0 (0)	7 (1)	11 (2)
65:34:1	6	14 (2)	25 (2)	36 (3)	50 (3)
65:33:2	6	13 (2)	17 (2)	20 (2)	35 (3)
65:32:3	6	13 (2)	16 (2)	19 (2)	28 (2)
65:31:4	6	1 (1)	8 (1)	20 (2)	26 (2)
70:29:1	4	23 (2)	45 (3)	70 (4)	84 (5)
70:28:2	4	21 (2)	45 (3)	56 (4)	73 (4)
70:27:3	4	11 (2)	30 (2)	40 (3)	59 (4)
70:26:4	4	9 (1)	18 (2)	35 (3)	55 (4)

Source: ASTM (2003). (): Rating scale; 0: No mold growth; 1: Slightly growth (10%); 2: Low staining (11-30%); 3: Moderate staining (31-50%); 4: High staining (51-75%); 5: Severe (>75%)

than those WPC boards with higher wood fines loading. This may indicate that WPC board with higher wood fine loading exhibit more wood surfaces area for mold to be attacked. In addition, WPC boards produced with higher MAPP loading especially with 4% are highly resistance to mold. Pendleton *et al.* (2002) reported that all WPC exit interfacial gap between the wood fine and the polymer matrix. The mycelium will appear to be concentrated in the gap between the wood and the thermoplastic component near the specimen surface. The used of coupling agents are served to be the bridge that reduced the gaps between wood and polymer matrix. It has been reported that WPC formulation with high MAPP loading appears to act as a gap-filler and prevents the mycelium to penetration into the material (Pendleton *et al*., 2002).

The overall scales of mold growth and coverage on WPC boards after 4 week of incubation period presented in Table 3. Again, the WPC boards with lower wood fine loading and higher MAPP loading showed less susceptible to mold.

Durability against decay fungi: Table 4 shows the mean weight loss and resistance class of WPC boards after exposed to fungus *Pycnoporous sanguineus* for 8 weeks, fungus colonization was visually observed on the surface of all the WPC boards. Nonetheless, all the WPC samples had very low percentage of mean weight loss, which were classified as highly resistant (0-2.85%) compared to control sample which rated as susceptible to decay fungi attack.

WPC produced with 70% wood fine loading had higher mean weight loss than those WPC with 60% and 65% wood fine loading. Similar result was also observed by Khavkine *et al*. (2001), they found little weight loss caused by fungal attack for polyethylene composites containing 40 to 70% wood, despite good fungal colonization on the composite surfaces and a conditioning procedure that included oven drying at 105°C for 24 h, a 2 h boil and a 24 h water soak.

Durability against termites: Table 5 shows the mean weight loss, termite mortality and visual attack rating of WPC boards, as shown in the table, WPC made from 70% wood fine 29% PP and 1% MAPP had the highest mean weight loss (4.21%) compared to the other formulations. Previous researchers (Lee *et al*., 2004; Markarian, 2005) revealed that the weight loss increase as the wood fine loading increased. This may due to wood plastic composites with high wood fine loading can be eaten by termites at any wood portion throughout the composite that is not fully encapsulated by polymer matrix. Wood fine which contains cellulose was one of the food sources for termites.

Table 4: Durability of WPC boards against decay fungi

Treatment	Mean weight loss (%)	Resistance class
Control	26.74	Moderately resistant
60:39:1	0.52 (0.47)	Highly resistant
60:38:2	0.91 (0.90)	Highly resistant
60:37:3	0.00 (0.00)	Highly resistant
60:36:4	0.09 (0.20)	Highly resistant
65:34:1	0.66 (0.62)	Highly resistant
65:33:2	1.18 (1.11)	Highly resistant
65:32:3	0.28 (0.25)	Highly resistant
65:31:4	1.24 (1.10)	Highly resistant
70:29:1	1.08 (0.60)	Highly resistant
70:28:2	2.33 (1.05)	Highly resistant
70:27:3	1.27 (0.29)	Highly resistant
70:26:4	2.85 (1.13)	Highly resistant

Source: ASTM (1978). All the data are based on average value from five specimens. () Standard deviation

Table 5: Mean weight loss and mortality of WPC produced at different wood fine loading and MAPP percentage

		Termite bioassay		
Rubberwood fine loading (%)	MAPP (%)	Mean weight loss (%)	Mortality[a] (%)	Visual rating[b]
Control(pine)	-	20.18	26.01	4.0
	1	1.53 (0.74)	100 (0)	9.8
60	2	0.53 (0.98)	100 (0)	9.8
	3	0.43 (0.43)	100 (0)	9.8
	4	0.53 (0.54)	100 (0)	9.8
	1	2.15 (0.37)	100 (0)	9.8
65	2	0.85 (0.18)	100 (0)	9.6
	3	0.88 (0.76)	100 (0)	9.6
	4	0.8 (0.51)	100 (0)	9.6
	1	4.21 (0.70)	100 (0)	9.6
70	2	1.76 (0.08)	100 (0)	9.4
	3	1.11 (0.37)	100 (0)	9.4
	4	1.07 (0.11)	100 (0)	9.4

Source: ASTM (1980). Reapproved 1980. [a]Mortality rating: 0-33%, slight; 34%-66%, moderate; 67%-99%, heavy and 100%, complete. [b]Termite attack rating scale: 0: Failure; 4: Heavy; 7: Moderate attack; 9: Light attack; and 10: Sound. ()Standard deviation

WPC boards added with higher MAPP loading had lower mean weight loss compare to board with 3, 2 and 1% MAPP and control specimens. This may proved that adding MAPP in WPC formulations play a very important role in improving the compatibility and adhesion between polar wood fines and non-polar polymer. WPC produced with different wood fine loading and MAPP percentage were found to be equally effective against subterranean termites where the entire termite in the testing bottles had 100% mortality compare to 26.01% mortality rate in control sample. The mortality of termite correlates with the total amount of wood loss. Femi-Ola *et al.* (2007) stated that there was a high degree of correlation between the amount of wood consumed and survival of *Amitermes evuncifer*. This may explained the result of higher weight loss was observed for the control samples in this study.

CONCLUSIONS

Conclusively, WPC produced with higher wood fine loading and lower MAPP concentration experienced poor durability against common biodegradable agents in Malaysia. This may due to insufficient encapsulation of wood fine with polymer matrix. The WPC produced with formulation of 4% MAPP and 60% wood fine loading gave best performances on the biological durability test in this study.

REFERENCES

ASTM, 1978. Standard Method of Accelerated Laboratory Test of Natural Decay Resistance of Wood. American Society For Testing and Material ASTM D2017-71, Philadelphia, pp: 638.

ASTM, 1980. Standard Method Laboratory Evaluation of Wood and Other Cellulosic Materials for Resistance to Termites. ASTM, Philadelphia, PA.

ASTM, 2003. Standard Test Method for Fungicides for Controlling Sapstain and Mold on Unseasoned lumber (Laboratory Method). American Society For Testing and Material, USA., pp: 4.

Anonymous, 2009. Wood and Competitive Decking. The Freedonia Group's, Cleveland, Ohio, pp: 326.

Eder, A., 2009. Market information on wood plastic composite decking and siding in europe. Proceeding of the 3rd German WPC Congress. Dec. 2-3, Maritim Hotel Cologne, Nova-Institut, pp: 9-9.

Femi-Ola, T.O., E.Y. Aderibigbe and L.O. Awoyemi, 2007. Microbiology of the hindgut and survival of *Amitermes evuncifer* (Silvestri) on some Nigerian woods. Res. J. Microbiol., 2: 910-917.

Kamdem, D.P., H.H. Jiang, W.N. Cui, J. Freed and L.M. Matuana, 2004. Properties of wood plastic composites made of recycled HDPE and wood flour from CCA-treated wood removed from service. Composites Part A: Applied Sci. Manuf., 35: 347-355.

Khavkine, M., M. Kazayawoko, S. Law and J.J. Balatinecz, 2001. Durability of wood flour-thermoplastic composites under extreme environmental conditions and fungal exposure. Int. J. Polym. Mater., 46: 255-269.

Kim, J.W., D.P. Harper and A.M. Taylor, 2008. Effect of wood species on water sorption and durability of wood-plastic composites. Wood Fiber Sci., 40: 519-531.

Lee, S.Y., H.S. Yang, H.J. Kim, C.S. Jeong, B.S. Lim and J.N. Lee, 2004. Creep behavior and manufacturing parameters of wood flour filled polypropulene composites. Composite Struct., 65: 459-469.

Liu, J., 2009. Development of WPC industry in China. Proceeding of the 3rd German WPC Congress. Dec. 2-3, Maritim Hotel Cologne, Nova-Institut, pp: 9-10.

Markarian, J., 2005. Wood plastic composites: current trends in materials and processing. Plastics Additives Compounding, 7: 20-26.

Mitsuhashi, J. and J.J. Morrell, 2010. Ability of heating to enhance water uptake in wood/plastic composites. Pigment Resin Technol., 39: 174-177.

Morrell, J.J., N.M. Stark, D.E. Pendleton and A.G. McDonald, 2006. Durability of wood-plastic composites. Wood Design Focus, 16: 7-10.

Morris, P.I. and P. Cooper, 1998. Recycled plastic/wood composite lumber attacked by fungi. For. Prod. J., 48: 86-88.

Pendleton, D.E., T.A. Hoffard, T. Adcock, B. Woodward and M.P. Wolcott, 2002. Durability of an extruded HDPE/wood composite. Forest Prod. J., 52: 21-27.

Pilarski, J.M. and L.M. Matuana, 2006. Durability of wood flour-plastic composites exposed to accelerated freeze-thaw cycling. II. High density polyethylene matrix. J. Applied Polym. Sci., 100: 35-39.