International Journal of Engineering & Technology, 7 (4.18) (2018) 118-121

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Polypropylene/Luffa Wood Plastic Composites with High Fibre Loading

Siti Nur 'Aisyah Umar Syarifuddin[1], Raja Roslan Raja Mohamed[2], Ahmad Faiza Mohd[2], Engku Zaharah Engku Zawawi[1], Nur Hikamah Seth[3], Dzaraini Kamarun[1, *]

[1]Orchestrated Polymer Research Group, Faculty of Applied Sciences, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia.
[2]Faculty of Applied Sciences, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia
[3]Centre of Foundation Studies, Universiti Teknologi MARA Selangor, Kampus Dengkil, 43800, Malaysia
**Corresponding author E-mail: dzaraini@salam.uitm.edu.my*

Abstract

Conventionally, wood plastic composites (WPC) utilize wood fibres from timber industry waste as the source of natural fibres (NF). Non-wood fibres may contribute as an alternative source of fibres for WPC industries. Non-wood fibres such as those from kenaf, sugarcane, hemp, sisal and flax plant offer several advantages over wood fibres in terms of shorter maturation time and ease of planting and harvesting; hence greater sustainability. However, reported researches on non-wood NF plastics composites are confined to loadings of fibres less than 50%; diminishing their marketability as 'green' products. 'Green' WPC products should incorporate a minimum of 50% NF (biodegradable component) in order for it to be readily recognized and accepted by consumers and trade holders. This paper discussed the development of a WPC based on luffa fibre with loadings of up to 65%. Luffa fibre originates from the matured fruits of luffa plants locally planted for food consumption before maturation. Polypropylene was selected as the polymer matrix due to its low cost and good mechanical properties compared to other thermoplastics such as PE and PVC. Four formulations of PP/luffa were developed at 50, 55, 60 and 65 % fibre loading and test pieces were prepared using an injection molding machine. Formulations of the composite included maleic anhydride grafted polypropylene (MAPP) as coupling agent and Cloisite 15A as fillers. Tensile, impact and fracture properties were determined and compared with several wood-based WPCs reported in the literature. The impact and fracture properties are comparable if not better than the wood-based WPCs. The tensile strength is however lower than the cited wood-based WPCs probably due to inhomogeneity and insufficient distribution of fillers in the PP/luffa composites. As a conclusion, PP/luffa WPC has the potential to be used as an alternative injection molded 'green' WPC product with properties comparable to wood-based WPC; and added advantage of greater sustainability.

Keywords: *green composites; luffa; non-wood fibres; wood fibres; wood plastic composites.*

1. Introduction

Wood Plastics Composites (WPC) is gaining wider interest and popularity due to its unraveled properties and contribution. Wood or natural fibers (NF) incorporated in WPCs as fillers are replacing the more expensive and non-biodegradable inorganic fillers such as glass and carbon fibers. About 400,000 tons of WPC are produced in Europe every year [1] marking the importance of these fibers as renewable, environmental friendly, lightweight and less abrasive (to processing equipment) materials with higher aesthetic value. Moreover, life cycle assessment and cost analysis of products incorporating natural fibers as alternative to glass fiber revealed that NF hybrid materials are cost-competitive with current glass fiber composite materials; and they out-performed the existing material in terms of cumulative energy required for the entire production phase by about 46% of the manufacturing energy cost [2].

Furthermore, WPCs can be readily processed by conventional plastic processing techniques such as extrusion, injection and compression molding. Natural fibers that had been used in WPC are categorized into wood and non-wood fibers. Both types of fibers consist of the same basic chemical structures of cellulose, hemicellulose and lignin but differ in their concentration [3]. Non-wood fibers have an additional component, pectin which is a soluble dietary fiber. Major applications of wood are still dominated as energy source, wood pulp and paper industry. Applications of wood fibers in WPC are limited to sawdust, wood powder and wood flour from timber industry waste that contains contaminants such as adhesives, resins and coatings. Subsequent treatments or process adaptations with added cost are usually required before the introduction to WPC production [4]. Furthermore harvesting of wood could lead to deforestation and result in environmental sustainability problem. Nevertheless, wood fibres contribute the highest consumption in WPCs (80%) compared to non-wood fibres [5]. Non-wood fibers such as hemp, kenaf, sisal, coir and bamboo have added advantage compared to wood fibres in terms of shorter maturation time and ease of planting and harvesting. Shorter maturation time leads to increased number of harvest per year hence higher production.

Being commodity plastics, thermoplastics precede thermosets in terms of its consumption in WPCs. The most common thermoplastics used in WPCs are high and low density polyethylene (HDPE and LDPE), poly(vinyl chloride) (PVC), and polypropylene (PP). PP dominates over PE and PVC in terms of the number of PP-based WPC reported in the literatures [6]. PP is characterized as easily-processed and low-cost, and possesses good mechanical properties. The biggest setback of PP is its low impact strength, which limits its practical application. Natural fibres incorporated into PP-based WPCs ranged from wood of various origins such as maple, timber, spruce, pine, fir and cedar to non-wood fibres such as sugarcane bagasse, rice straw, hemp, flax, jute and sisal. These non-wood fibres commonly used in PP-based WPCs are bast fibres obtained from the plant's stem.

High fibre loading WPC shared the advantages of having low volume of non-biodegradable plastics with comparable if not superior mechanical properties compared to its low loading WPC. Moreover it offered smart maintenance since WPCs generally have no need for surface treatments such as polishing, painting or others.

In this study, properties of PP/luffa WPC are described and compared to other PP/wood-based WPCs. Luffa fibre is obtained from the fruit of a luffa plant, locally planted for consumption as vegetable. For application in WPCs, matured luffa fruit are used. The creeper plant does not require vast land; and a higher yield of the fruit could be obtained by using a trellis support system. Luffa fruit reaches maturity in less than four months as compared to bast fibers such as kenaf which is 5 months; thereby making it an economical alternative. Traditionally, young luffa fruit are consumed as food while the matured and over matured fruit are used as scrubbing sponge and as a root medium in hydroponic plant growing system; otherwise disposed as domestic or agricultural waste. Industrial application of the fiber from matured fruit as a biocomposite material gives added value to the fruit as well as increases the socio-economic status of local planters.

2. Materials and Methods

2.1. Preparation of PP/Luffa WPC©

2.1.1. Materials and Chemicals

PP pellets manufactured by Etilinas Sdn Bhd. were obtained in granular form. Luffa fibers were obtained from matured fruits at a local farm in Malacca. Polypropylene-graft-maleic anhydride (MAPP) with 8-10% of maleic anhydride (melting point 156°C; density 0.934 g/cm3) was from Aldrich Chemistry. Cloisite 15A (density 1.4-1.8 g/cm3) from Southern Clay Products, Gonzales Texas, USA was used as additives. It is a type of clay based on natural montmorrilonite modified with dialkyldimethylammonium chloride.

2.1.2. Formulation and Fabrication of PP/Luffa WPC©

Oven-dried (80°C for 24 hrs) luffa fibres were crushed and mesh sieved on a 30 mesh size siever (0.6 mm). The compounding of PP, luffa fiber, maleic anhydride grafted PP (MAPP) as compatibilizer and Cloisite 15A was carried out in a Compounder Brabender twin screw extruder machine (MODEL E46) (Screw L:D ratio is 40:1) at 190°C barrel temperature and roller speed of 50 rpm. Pressure was fixed at 48 bar. Extrudates were cooled by the conveyer belt and cut into pellets using the pelletizer machine. These pellets were oven-dried at 80°C for 12 hours before making test specimens. Several formulations of the composites were fabricated as shown in Table 1. Composition of Luffa fiber was varied at 5 wt% increment from 50 wt% in L50 to 65 wt% in L65. Composition of Cloisite 15A was fixed at 5 wt% in all formulations.

Table 1: Composition of various PP/Luffa WPC©

Sample	Luffa (wt %)	Polypropylene + MAPP (wt %)	Cloisite 15A (wt %)
L50	50	45	5
L55	55	40	5
L60	60	35	5
L65	65	30	5

2.2. Density and Mechanical Properties of PP/Luffa WPC©

Densities of all materials were determined using a densitom-eter. Ray Ran injection molding machine was used to pre-pare test pieces for tensile, impact and flexural strengths of the composites. The barrel and tool temperatures were fixed at 195°C and 100°C respectively. Filling time varied from (3-20) s while the pressure from (70-115) psi depending on type of test pieces fabricated. Impact samples required the least amount of filling time and lowest pressure while flexural samples required the most time and highest pressure.

Tensile test (ASTM D68) was conducted using the Testomet-ric Universal Testing Machine with a 5 kN load cell at cross head speed of 50 mm/min. Izod impact strength test (ASTM D256) were conducted using 4 Joules pendulum of impact energy and 3.5 m/s speed of hammer at room temperature. The flexural test was carried out according to to the standard D790 using the same machine as in the tensile test at ambient temperature. The flexural test included the calculation of the support span and the speed of the cross head. The length of the support span was 16 times the average thickness.

2.3. Water absorption of PP/luffa WPC©

The test pieces were prepared by cutting them into (10 x 10 x 0.1) cm dimension. All test samples were dried at 70°C until constant weight was achieved. The samples were then im-mersed into distilled water bath at 25°C for several period of time. After the predetermined period the samples were wiped dry and weighed. The water absorption of the samples was calculated using the formula in Equation 1.

$$\text{Percentage of water absorption} = \frac{(Mt - Mo)}{Mo} \times 100 \quad (1)$$

where:
M_t is the mass after being immersed into water
M_0 is the mass of sample at time, t = 0

3. Results and Discussion

3.1. Mechanical properties of PP/Luffa WPC©

Table 2 shows the mechanical properties measured of the various WPCs. Data for PP was also taken as reference. Tensile strength and modulus of rupture, MOR of the composites are lower than blank PP; all 4 composites showed an average tensile strength of 17.7 MPa and average MOR of 51.2 MPa. However, the impact strength of the composites and their modulus of elasticity, MOE are higher than PP blank with average values of 31.5 Jm^{-1} and 5.5 GPa respectively. TS and MOR are affected by composition of PP. MOR is the maximum load carrying capacity of a material. It is a measure of strength. Fibre incorporation reduces the composition of PP in the composites which cause the reduction in TS and MOR of the composites. However, IS and MOE of the composites are higher than blank PP. MOE is a measure of the resistance to bending deflection and deformation at low stress value below the elastic limit which contribute to toughness of a material. Presence of crosslinked lignin in the fibre contributes to the toughening of the composites.

Table 2: Mechanical properties of PP/Luffa WPC©

Samples	Density/gcm^{-3}	Tensile strength/MPa	Impact strength/Jm^{-1}	Modulus of rupture/MPa	Modulus of elasticity/GPa
PP	0.95	28.7±1.3	18.5±1.4	62.2±0.5	2.3±0.1
L50	1.08	18.3±1.6	28.8±0.8	50. 3±1.5	4.7±0.2
L55	1.10	17.5±0.6	30.2±0.6	49.8±0.5	5.3±0.2
L60	1.14	17.4±0.6	34.1±1.1	52.9±1.5	6.1±0.2
L65	1.10	17.7±1.1	32.8±2.8	51.6±1.5	5.7±0.3

Table 3: Techniques and properties of composites

Item	Processing technique	Fibre Type	Fibre content in WPC (% (w/w)	% MAPP	TS/MPa	MOE (GPa)	MOR (MPa)
WPC1 [7]	Injection molding	Wood ind. waste	50	2	40	4.6	44
WPC2 [8]	Injection molding	Wood ind. waste	47	3	27	5.7	-
WPC3 [9]	Compression molding	Wood ind. waste	50	5	38	5.2-6.8	-
WPC4 [10]	Compression molding	Wood ind. waste	50	4	25	2.3	25
WPC5 [11]	Compression molding	Luffa	50-65	2	6-11	2.3-2.7	17-19
PP/Luffa WPC©	Injection molding	Luffa	50-65	2	~18	4.7–6.1	50 - 53

3.2. Comparison of high fibre loading PP/Luffa WPC© with Wood-based WPC

Mechanical properties of PP/wood WPCs (WPC1 – WPC5) with 50 % (w/w) fibre loading reported by several researchers are compared with PP/luffa WPC© in the current study. The WPC were prepared by two techniques i.e. injection and compression moulding. Table 3 summarized the techniques and properties of composites produced as reported by these researchers

For a given fiber content, the WPCs that were prepared via injection moulding (WPC1 and WPC2) show a better mechanical properties than those using compression moulding technique (WPC3, WPC4 and WPC5). These could be expected due to a good fiber and filler distribution during the mixing process in injection moulding machine where a greater interaction between the hydrophilic parts in both filler and fiber leads to a well-distributed filler and fiber system. This is supported by Xu et. al [12] stated that improvement of mechanical properties for structural engineering applications can be obtained if the wood fibers are properly blended with the polymers.

Nevertheless, at high MAPP content, the dependence of the mechanical properties on the processing technique is averaged out. WPC3 which was prepared via compression moulding technique with 5% MAPP content have a better tensile strength and MOE compared to WPC4 and WPC5 with lower MAPP content. It shows that MAPP contribute to better interaction between those fillers and fibers in that system [8, 13].

Furthermore, it was interesting to note from the modulus results in Table 3 that the differences in the MOR and MOE between wood based composites and PP/Luffa WPC© in the present study were negligible. In other words, the PP/Luffa WPC© shows comparable performance to wood based WPCs and therefore served as a novel WPC with high fibre loading.

3.3. Water absorption of PP/luffa WPC©

Fig. 1 displays the percentage of water uptake by composite samples every 24 hrs. for 6 days. The hydrophobic character of PP prevent the diffusion of water molecules into the matrix thus do not show any tendency to absorb water. Incorporation of luffa fibre in the composite system allowed water to be absorbed due to the hydrophilic nature of luffa fiber [14]. As expected water absorption increased with increased of luffa loading in the composites. LP60 with 60% fibre loading shows the highest value of water absorption as compared to the other composite samples. Interestingly, at 65 % fiber loading the water uptake decreased; and the decreased corresponded closely to water absorption of LP50 (Table 4). This could probably be due to the compactness of the composite structure in LP65 as shown by its density (Table 2) which prevents or caused slow diffusion of water into the bulk of the composite. As a result absorption of water in LP65 could probably be limited to the surface of the composite thereby reducing the overall water absorption.

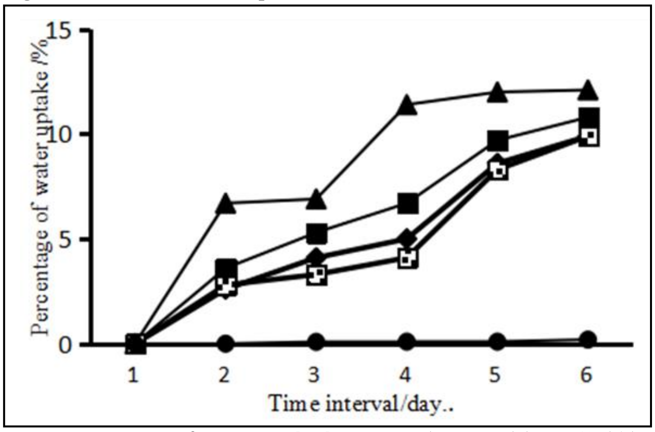

Fig. 1: Percentage of water uptake by LP50 (♦), LP55 (■), LP60 (▲), LP65 (□) and virgin PP (●) at time intervals of 1 day.

Table 4: Percentage of water uptake by composite samples

Sample	Water absorption (%)					
	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
PP	0.0	0.0	0.0	0.0	0.0	0.0
L50	0.0	2.6	4.1	5.0	8.6	9.9
L55	0.0	3.6	5.3	6.7	9.7	10.8
L60	0.0	6.7	6.9	11.4	12.0	12.1
L65	0.0	2.8	3.3	4.2	8.3	9.9

4. Conclusion

The higher the amount of NF in WPC compounds the more attractive it is in terms of its property as ‘green’ product and hence environmental friendly. The uppermost amount of NF in WPC reported is 50%. We successfully injection molded PP/Luffa WPC with 65% luffa. The properties are comparable to other high fibre loading wood-based WPC. PP/luffa WPC with 65% luffa prepared in this project showed interestingly low water absorption properties which could form the basis for producing WPC with high NF loading and hence 'greener' products.

Acknowledgement

The authors would like to thank Institute of Research Management & Innovation (IRMI), Universiti Teknologi MARA for their support and assistance in securing the research grant 600-IRMI/PERDANA 5/3 MITRA (003/2018) awarded for this research.

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