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Fracture Properties Investigation of *Artocarpus odoratissimus* Composite with Polypropylene (PP)

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Abstract

Wood plastic composites (WPC) were done using a matrix of polypropylene (PP) thermoplastic resin with wood fibre from *Artocarpus odoratissimus* as filler. The purpose of this study is to investigate the fracture properties of *Artocarpus odoratissimus* composite with PP. The WPC was manufactured by a hot - press technique with varying formulations which are 10:0 (100% pure PP), 50:50 (40 g of wood fibre and 40 g of PP) and 60:40 (48 g of wood fibre and 32 g of PP). The mechanical properties were investigated. Tensile and flexural were carried out according to ASTM D 638 and ASTM D 790. The results were analysed to calculate the tensile strength. Tensile strength at break is ranged from 13.2 N/mm^2 to 21.7 N/mm^2. While, the flexural strength obtained is varying from 14.7 N/mm^2 to 31.1 N/mm^2. The results of the experiment showed that tensile and flexural properties of the composite increased with the adding of wood fibre material. Finally, the Scanning Electron Microscope (SEM), have been done to study the fracture behaviour of the WPC specimens.

Keywords: WPC; *Artocarpus odoratissimus;* Polypropylene thermoplastic; Wood fibre

Introduction

Wood-plastic composites (WPCs) are emerging as one of the dynamic growth materials in the building industry. WPC is manufactured by dispersing wood particles into molten plastic with coupling agent or additives to form a composite material through various techniques of processing such as extrusion, compression or injection moulding. It was first made commercially from phenol-formaldehyde and wood floor that was used for Rolls-Royce gearshift knob in 1916, and it was reborn as a modern concept in Italy in the 1970s, and popularized in North America in early 1990s [1]. Wood-thermoset composites date back to the early 1900s; however, thermoplastic polymers in WPC are a relatively new innovation. In 1983, an American Woodstock company (Lear Corporation in Sheboygan, WI) began producing automotive interior substrates by using extrusion technology from the mixture of polypropylene (PP) and wood flour [2]. Since then production and market demand for the WPCs have been growing rapidly worldwide. Currently WPCs are mainly used for building products like decking, fencing, siding, garden furniture, exterior windows and doors [3,4], although other applications can also be found in marine structures, railroad crossties, automobile parts and highway structures such as highway signs, guardrail posts, and fence posts [5]. WPCs possess many advantages over the raw materials of polymers and wood filler. WPC had better dimensional stability and durability against bio-deterioration as compared to wood. In addition, WPC also reduces the machine wear and tear of processing equipment, and lower the product cost against inorganic fillers when waste streams such as sawdust are used [4]. As compared to the polymers, WPC had higher mechanical properties, thermal stability, and more resistance to the ultraviolet light and degradation [6-10].

Similarly, large amount of wood waste generated at different stages in the wood processing is mainly destined for landfill. It was reported that waste wood in the form of wood flour, fibres or pulp is suitable as filler for polyolefin's matrix composites. *Artocarpus odoratissimus* wood fibres possessed physical and mechanical properties suitable to the reinforcement of plastics. Hence increased usage of the recycled plastics and the waste wood for WPCs offers the prospect of lessening waste disposal problems and lowering production costs.

Virgin thermoplastics such as HDPE and polypropylene (PP) are widely used for WPCs, and a significant number of papers are available for their mechanical properties, dimensional stability, interface adhesion and durability.

In conclusion, stability and durability performance of WPCs based on post-consumer thermoplastic are not fully understood and the affecting factors are not known, leaving open research opportunities for the optimization of formulation and processing. WPCs performance can be optimized by investigating a wide range of composite formulations and processing techniques. Considering the potentials for applications and resource availability, PP was chosen as the raw materials to produce the WPCs with wood fibre from *Artocarpus odoratissimus* wood through the compression moulding. Mechanical properties need to be investigated. Influence of polymer type and form (virgin) and *Artocarpus odoratissimus* wood fibre was also examined.

Methodology

Wood fibre, as shown in Figure 1 used in this project is obtained from the *Artocarpus odoratissimus* tree at the Kg. Kebayau, Telipok, Sabah. The wood fibres as solid waste were derived from the tree by using a chainsaw and the waste of the wood produce by chainsaw the tree was collected.

The wood fibre was ground to have required 40-80 mesh size of the fibre and then screened to remove impurities. It was then dried in an oven at 103 ± 2°C for 24 hours to a moisture content of 2%. These

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fibres are kept in airtight bags to avoid high humidity which would allow moisture ingression into fibres (Table 1).

The type of resin used in this project is polypropylene (PP) thermoplastic resin (Table 2). This resin is obtained from Chemical Laboratory as shown in Figure 2 and was used as a matrix. Table 3 shows the properties of the polypropylene (PP). Besides that, this resin's attributes include light weight (low specific gravity), high temperature resistance, good chemical resistance, excellent rigidity, no stress cracking, high tensile strength, excellent flexural strength, low creep, excellent electrical properties, good barrier properties, impact resistance, wide range of applications, ease of processing and highly environmental friendly.

The wide range of physical properties via modification, ease of processing, and cost advantage of polypropylene, make it an extremely attractive alternative to more expensive resins in a number of applications.

Figure 1: *Artocarpus odoratissimus* wood fiber.

Code	Value	Fiber length (μm)	Fiber diameter (μm)	Lumen diameter (μm)	Wall thickness (μm)
Pith	Average	952.9	20.97	13.23	7.74
	Standard deviation	150.75	5.17	3.85	3.25
Core	Average	1294.28	35	16.21	9.4
	Standard deviation	230.69	5.87	6.05	3.88
Transition	Average	1260	26.21	16.05	5.08
	Standard deviation	203.4	6.29	5.09	1.7
Sapwood	Average	1286.43	28.47	17.1	5.69
	Standard deviation	221.31	5.93	5.28	2.5

Table 1: Dimension value of *Artocarpus odoratissimus* wood fiber.

Code	Value	Runkel Ratio	Power loom	Muhlstep Ratio	Coefficient of Rigidity (CR)	Flexibility Ratio (FR)
Pith	Average	0.67	47.91	37.18	0.19	0.63
	Standard Deviation	0.56	13.38	9.57	0.05	0.10
Core	Average	0.70	37.74	39.32	0.20	0.61
	Standard Deviation	0.34	8.08	9.42	0.05	0.09
Transition	Average	0.69	50.11	39.19	0.20	0.61
	Standard Deviation	0.30	11.89	10.19	0.05	0.10
Sapwood	Average	0.78	47.01	39.67	0.20	0.60
	Standard Deviation	0.57	12.92	14.39	0.07	0.14

Table 2: Properties of *Artocarpus odoratissimus* wood fibers.

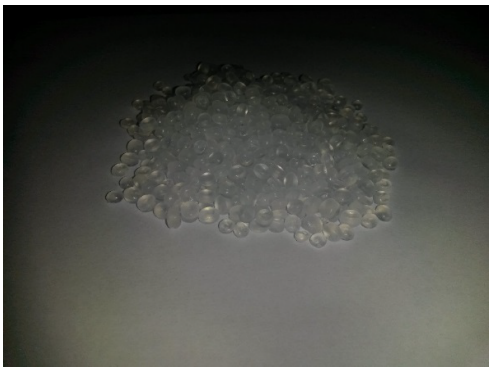

Figure 2: Polypropylene (PP) thermoplastic.

No.	Properties	Unit	Analysis Report
1.	Density	g/cm^3	0.9
2.	Melt flow index	g/10 min. 2.16 kg/190°C	25
3.	Tensile strength	MPa	26.48
4.	Elongation	%	-

Table 3: Properties of Polypropylene (PP) thermoplastic.

The specimen of the WPC was formed by using concrete. The median size is 150 mm × 150 mm × 150 mm. This mould is heated in an oven at temperature of 190°C to 210°C for a day before using. The used of this mould will be explained in the preparation of the Wood Plastic Composite (WPC).

The specimens of WPC were through hot-pressed method. Matrix material which is PP thermoplastic is reinforced with *Artocarpus odoratissimus* wood fibres. These materials are mixed well in a ratio of 71.43:28.57, 57.14:42.86 and 50:50. This ratio was determined by different weight percentage between thermoplastic and wood fibres respectively, and the three panels of the dimensions of 150 mm × 150 mm surface area with different ratios were manufactured.

In the first process of manufacturing the wood, plastic composites, the wood fibres and thermoplastic resin were mixed well in hand by the container. Then, the mixing was put into a mould that has been heated in the oven a day before uniformly. Next, a steel plate is a plate on the composite materials mixing as a cover for the hot - pressed process to obtain flat surfaces. Compressive strength machine was used to compress the composite materials mixing, which is much more similar to actual hot-press method and the pressure applied was around 200-250 kN.

The mould was placed at the centre point position in the compressive machine with the lab technician conduct and helps. Rod was put in the mould for compressing purposes. The mixing was pressed by the machine which is conducted manually around 5 minutes. After the compression done, the campsites were taken out of the mould and left at room temperature for a while. Finally, six of rectangular shapes specimens with 100 mm × 25 mm for mechanical testing were produced.

Tensile test is aimed to obtain tensile properties. Tensile test is commonly used to determine mechanical properties such as strength, toughness and modulus of elasticity. There are 3 specimens for the three

different compositions. The tensile test was run by using the GOTECH/AI-7000M Electronic Mechanical Testing. All these samples have been cut according to ASTM D638 and will be used in the tensile test.

All the specimens are tested using the Electronic Mechanical Testing with a speed rate of 1 mm/min. Samples are placed in the grips of the machine at specified grip separation and pulled until failure. The machines will automatically produce a stress versus strain diagram, thus the mechanical behaviour of the composites can be interpreted from the diagram. The specimen will elongate as the tensile test starts. The load value (F) is recorded up to the point where the specimen breaks. The instrument software, which is provided with the machine equipment, will calculate the tensile properties such as the tensile, yield strength and elongation.

Tensile and flexural tests have been performed and the mechanical properties such as tensile strength and tensile modulus were determined. In this project, there were 3 specimens prepared. The test specimens were cut into the dimension of 100 mm × 25 mm (Figure 3).

Result and Discussion

The aim of this paper is to establish mechanical properties such as tensile strength and flexural strength of the wood plastic composites with different formulations. Basically, three main tasks were carried out in order to achieve the objectives of this project. The first task is to prepare the wood, plastic composite by combining wood fibre from *Artocarpus odoratissimus* and polypropylene thermoplastic resin. This is followed by performing the tensile and flexural tests, and lastly, a microstructure analysis is carried out to study the fracture behaviour of the wood plastic composites specimen.

Figure 3: The specimens of wood plastic composites prepared for mechanical properties.

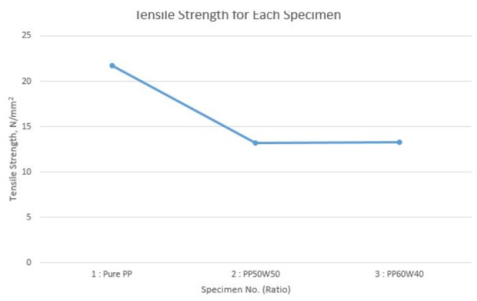

Figure 4: Tensile strength for 3 specimens of different ratio.

The results of the tensile strength and flexural properties of the wood-PP composites are given in Table 3. As it can be seen from the table, the tensile strength of the wood, plastic composites lay in the range of 13.2 N/mm^2 to 21.7 N/mm^2 depending upon composite formulations. The composites based on pure PP exhibited higher tensile strengths, compared to those based on PP for 50 wt. % wood fibre content. For example, with a plastic to wood ratio of 50:50, composite based on VPP was 13.2 MPa. This is because of higher molecular weight of virgin PP (25 g/10 min. 2.16 kg/190°C) as MFI is inversely proportional to MFI. The tensile strength increases with molecular weight due to the effect of better entanglement.

The flexural strength (MOR) and Young's modulus (MOE) were obtained from 3 points bending tests and values are given in Table 4. The flexural MOR exhibited a similar trend as the tensile strength. The composites had a flexural MOR varying from 14.7 Mpa to 31.1 MPa. It was also observed that the MOR increases with decreasing wood content as expected from the rule of mixtures, the addition of wood fibres into the PP matrix significantly increased MOE of the composites and MOE value increased with the wood content. It was observed that for the non-coupled composite formulations, incorporation of wood fibres into the PP matrix did affect the MOR more as compared to MOE. The yield strength of composites followed the similar trend as that of flexural MOR for all composite formulations. The load-displacement curves of the pure PP composites and the wood, plastic composites are shown in Figures 4 and 5, which illustrates the effects of the filler loading. The load-displacement curves for the wood, plastic composites had relatively high slopes initially, but as a failure occurred, the loads dropped off quickly as the material crumbled. However, the pure PP specimen reached ultimate capacity after significant deformation (15 mm in this case), and then the load decreased gradually until the test was concluded, indicating ductile behaviour. The addition of wood fibre in the composites increased the stiffness and brittleness, however, reduced the elongation at break. The stress concentration at the fibre ends and poor interface bonding between wood and PP matrix have been recognized as the main causes for the embrittlement (Figure 4).

However, during loading, fractures occurred at the filler locations, and these fracture locations were more brittle than other parts of the matrix. Hence, these composites showed little change in the specimen appearance in the initial stage of loading until the maximum load was reached when the specimen failed suddenly with extensive breakage at the interface between the wood fibre and the matrix. The elongation at break of the wood, plastic composites was much lower than that of the pure PP panel. This decrease was probably due to the higher degree of brittleness introduced by the incorporation of wood fibres in the PP matrix. As in the case of modulus, improving the adhesion between fibres and PP did not enhance elongation at break.

Specimen code	Flexural Properties				Tensile Strength (MPA)
	MOR (MPA)	MOE (GPa)	Yield Strength (MPa)	Elongation at break (%)	
Pure PP	31.1	1.25	17.3	3.70	21.7
PP50W60	14.7	1.68	7.9	1.55	13.2
PP60W40	22.0	1.71	11.1	2.50	13.3

Table 4: Tensile and flexural properties of the wood plastic composites.

The tensile and flexural properties variation of composites based on wood fibre and PP can be explained differently. It was found that composites exhibited higher tensile and flexural properties (Figure 5).

The morphology of surface structure of wood, plastic composites was investigated by SEM. SEM images of the wood; plastic composite at filler loading of 50 wt. % matrix is shown in Figure 6, in 200x magnification. From these images, it is clearly observed that there were distinct cluster and gaps between thermoplastic polymer matrix and wood. The patterns from wood fibres that were so weakly bonded to the matrix had been released from the matrix during fracture. The failure surface was undulated with clear wood fibre surfaces with visible tragedies, and laymen, indicating the path of weaker part through the wood-wood interface and weakest thermoplastic polymer matrix. This suggests that the interface between the wood fibre and PP matrix was weaker due to the poor dispersion and wettability. In some cases, the part of the wood lumen was filled with plastic that could increase the strength of the composites because of mechanical interlocking. When wood content was increased, the thermoplastic polymer matrix was no longer continuously distributed and many wood fibres were in direct contact with one another, resulting in poor bonding adhesion at the interface.

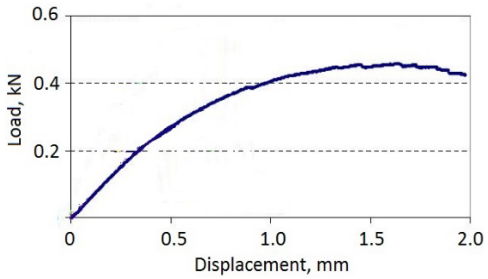

Figure 5: Load displacement curves for the specimen Pure PP.

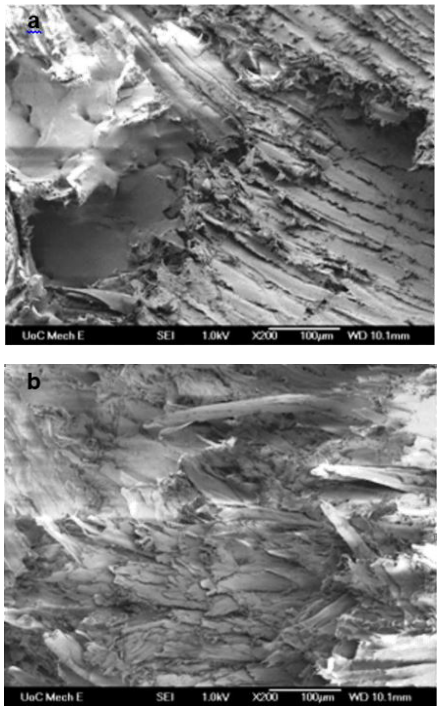

Figure 6: (a) and (b) are SEM images of the specimen PP50W50 with Magnification 200X.

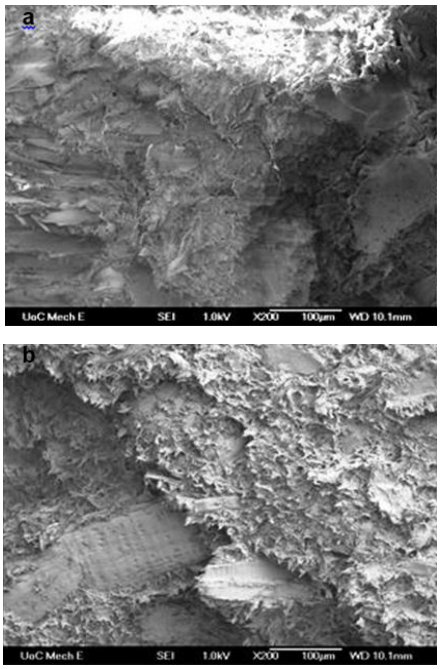

Figure 7: SEM images (x200) of fractured surface of PP60W40.

Mechanical bond is a form of adhesive bonding which adhesive material physically locks into the crevices of the surface. There are two or more separate components of interlocked molecules which are not connected by chemical or covalent bonds. The valleys and crevices of each fibre must filled with matrix and displace trapped air to work well. Matrix and fibre are mechanically interlocked together by adhesion and the overall strength of the bond is dependent upon the quality of this interlocking interface as explained in Bonding Adhesives in the year, 2000 as reported by D. Hull and T. W. Clyne in the year 1996.

However, this compatibility can improve when fibre treated by chemical treatment methods. Some research proved that treatment fibre increases the value of tensile strength by 53% as compared to the composites with untreated fibres. They also stated that the treatment improved the fober-matrix adhesion, allowing an efficient, and stress transfer from the matrix to fibres as studied by Morsyleide et al., and also by Herrera and Valadez. The composite seems to detach from the matrix and have relatively large pilots due to the poor interfacial bonding with the matrix. Hence, the role of treatment is mainly to remove impurities of the natural fibre, thus improving interfacial bonding.

The fracture surface of the composite showed a very limited amount of torn matrix, suggesting that the matrix was more brittle than those composites without coupling agent. It was also seen that a crack running through the wood fibre, and this could be an indication of stress-transfer from the matrix to the wood fibres. The interfacial bonding between the filler and the PP matrix was improved due to the esterification mechanism, and the fracture occurred at the filler itself. This means that the stress was well propagated between the filler and the matrix thermoplastic polymer, resulting in enhanced flexural strength and modulus in response to stress. In addition, the fracture surface showed a very limited amount of torn matrix, suggesting that the campsite was more brittle. In general, coupling agent was randomly distributed in composites and randomly reacted with wood fibres and the matrix to form graft polymerization. Hence, grafting sites was

randomly distributed on wood, and a network of coupling agent was formed at the interface (Figure 7).

However, there was a limit for chemical coupling reaction and only part of coupling agent was grafted onto wood surface and even cross-linked at the interface. Further, the fracture surface of the composite containing coupling agent showed a very limited amount of torn matrix, suggesting that the matrix was more brittle when higher weight. % of coupling agent added in the composite. This phenomenon was mainly due to the excessive modification of the base polymer.

It was observed that non-coupled composite samples had a weak interface region and damage mainly occurred along the loose and weak interface between the wood fibre and PP matrix under loading. However, with the coupling agent such as MAPP mix into composites, the wood fibre combined with the PP matrix through the covalent bonding or strong interfacial bonding, and the interfacial fracture usually accompanied with a cross section damage of wood fibre. Hence, after the failure, the fibre surface in the untreated composites was smooth; whereas the wood fibre in the coupling agent treated composites had a rough surface and it was embedded in the matrix with a chemical link. As the interracial bonding in the case of non-coupled composites were from mechanical connection, these composites failed mainly along the direction parallel to fibre length due to shearing failure between fibre bundles under bending.

Conclusion

Wood plastic composite have been successfully developed using *Artocarpus odoratissimus* wood fibre and polypropylene thermoplastic as reinforcements. Overall, the tension and flexural properties of the WPC show increase with increasing *Artocarpus odoratissimus* wood fibre loading. The value of tensile strength and hardness number of this composite material is higher than other existing composite material. This wood plastic composite is widely used for both indoor and outdoor decorations as well as office and high-grade furniture.

Acknowledgment

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