The Effects of Recycled Polypropylene/Wood Flour (r-PP/WF) Composites with and without Coupling Agent on Mechanical Properties

by

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Dissertation submitted in partial fulfillment of
the requirement for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Mechanical Engineering Programme
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Approved by,

(Dr. Mohamad Zaki Bin Abdullah)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
September 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

DAYANG FARHANA SYAFIAH BT ABG USOP

ABSTRACT

Plastic and wood have been indirectly causing global warming and developing domestic waste. Plastic is massively produced every day, so it contributes in high municipal waste generation rate and it is non-biodegradable. With depleting number of trees and forests, wood wastes are either burned or disposed which resulting in extra consumption, and pollution of nature. Therefore, by combining them into Wood Plastic Composite, we can recycle and reuse the product to replace current landscaping and furniture products. The main objective of this project is to study effects of different compositions on the mechanical properties of r-PP/WF composites and investigate the effects of coupling agent on the mechanical properties. Therefore, the scope of this project was focused on finding the composition of r-PP/WF that produces the best mechanical properties and investigating the effects of coupling agent on the composites. Thus, the methodology started with drying the WF, sieved the WF, granulated the r-PP, mixed r-PP and WF in the twin screw co-rotating extruder machine, then the pellets were hot-pressed in compression molding machine to create 20 cm x 15 cm x 0.4 mm plates, then cut into ASTM D638 (type I), ASTM 790 and ASTM 256 samples before proceed with the standard tensile, flexural and Izod impact testing. Then, the fractured samples were examined under SEM to see its microstructure. From the mechanical testing, the tensile strength of the composite reduced about 15% - 49% if compared to r-PP, but with coupling agent, the tensile strength improved 16% - 45%. While for flexural strength, the composites reduced 5% - 45% of its strength if compared to r-PP but improve 29% - 49% with coupling agent. On the other hand, flexural modulus improved up to 135% if compared to r-PP and the improvement by adding coupling agent is up to 80%. The impact strength also reduces 26% - 38% if compared to r-PP and slightly improvement done by coupling agent about only 2% - 12%. The best composite is 30% of WF, 65% of r-PP and 5% of FB. The microstructural analysis done by using SEM explains the mechanical properties behaviour. As a conclusion, the mechanical properties reduced probably due to processing techniques and the improvement done by coupling agent. The objectives of this project were achieved and this project proves that r-PP/WF composites are one of comparable alternative material for furniture and landscaping purposes.

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ABBREVIATION

ASTM	American Society for Testing and Materials
CO_2	Carbon Dioxide
EPDM	Ethylene/propylene/diene terpolymers
HDPE	High Density Polyethylene
ISO	International Organization for Standardization
IUPAC	International Union of Pure and Applied Chemistry
MAPP	Maleic Anhydride grafted Polypropylene
MFI	Melt Flow Index
LDPE	Low Density Polyethylene
PP	Polypropylene
PRSB	PETRONAS Research and Scientific Centre Sdn. Bhd.
PVC	PolyVinyl Chloride
r-PP/WF	Recycled Polypropylene – Wood Flour
SEBS-MA	Maleated styrene-ethylene/butylene-styrene tri block co-polymer
SEM	Scanning Electron Microscope
WF	Wood Flour
WPC	Wood Plastic Composites

CHAPTER 1
INTRODUCTION

1.1 BACKGROUND STUDY

1.1.1 Polypropylene

Polypropylene or its IUPAC name poly (propene) with molecular composition of $(C_3H_6)n$. Polypropylene also commonly known as PP, is a thermoplastic polymer used in various applications including food packaging, stationaries, kids furniture, outdoor furniture, house wares and synthetic textiles [1].

Polypropylene is an excellent resistance against organic solvents, electrolytic attack and degreasing agents. It can withstand higher working temperature since its melting temperature is higher than polyethylene. In addition, its tensile strength is also greater if compared to polyethylene. PP products are very light-weight, resistant to stain, and it has low moisture absorption rate, so it is suitable for outdoor furniture. Besides, it is very tough, heat-resistant, semi-rigid material which makes it ideal for transferring hot liquids or gases and act as insulator [2].

In the Table 1.1, it shows the mechanical properties of virgin polypropylene. As listed in the Table 1.2, PP is used as vast products in the market and the disposal of the products are what we need to minimize since it take decades of years to degrade.

Table 1.1: Properties of Polypropylene [3,4].

Property	**Value**
Density	0.905 g/cm^3
Modulus of Elasticity	1.14 – 1.55 GPa
Yield Strength	31.0 – 37.2 MPa
Tensile Strength	31.0 – 41.4 MPa
Percent Elongation	100 – 600 %
Fracture Toughness	3.0 – 4.5 MPa$\sqrt{m}$
Melting Temperature	175°C
Glass Temperature	-10°C
Water absorption – equilibrium (%)	0.03

Table 1.2: Polypropylene processing techniques [5].

Polypropylene processing	**Melt Flow Index (g/10 min)**	**End-user products**
Injection molding	10 – 20	Appliances, outdoor furniture
Thin wall injection molding	35 – 70	Food containers
Monofilaments	1 – 5	Bags
Staple fibers	10 – 30	Carpet backing
Continuous filaments	15 – 35	Carpet face
Spun-bonded fabric	30 – 40	Apparel, diapers
Melt-down fibers	>200	Apparel, diapers
Thermoforming sheet	1	Food containers
Slit tape	2 – 4	Woven fabric, geotextiles
Cast/blown film	6 – 12	Adhesive tape
Compression molding	2	Beverages caps
Blow molding	10 – 35	Bottles

1.1.2 Wood Flour

Wood is a very hard and high fiber tissue found in trees. For centuries, it has been used as construction material for houses, boats, jetty and furniture. It is an organic material, and a natural composite of cellulose fibers (which are strong in tension) embedded in a matrix of lignin which resists compression [6]. This combination makes wood very tough and strong.

Wood flour is finely ground wood that has a particle size almost the same as sand or sawdust, but it can vary significantly. Some particles can be as fine as fine powder to as coarse as rice. All high quality wood flour normally got from hardwoods because of its durability and strength. Large quantities of wood flour are frequently to be found in the waste from woodworking and furniture companies [7].

Since both PP and WF are usually abandoned from other industries, recycling the waste materials into a new material can save a lot of disposal cost. At the same time, we can create useful products from it with minimum cost since the resources are waste material, and the most important thing is we can save the environment.

The potential products from the r-PP/WF composites are decks, roofs, fences, benches, dustbin, furniture, doors and other structural that is currently using solid wood as the material. Besides that, wood is very good in water absorption which is not favorable in structural industries. Perhaps if we can proof that r-PP/WF is more durable than solid wood and water-resistant, then the r-PP/WF can be considered as alternative material to replace solid wood.

Table 1.3 shows the mechanical properties of two types of hardwood, which are Dauglas fir and Red Oak. Even though these woods do not exist in Malaysia, but *Meranti* (Shorea), or *Belian* (Eusideroxylon zwageri) are the comparable hardwoods that easily can be found in Malaysia.

Table 1.3: Properties of wood [3].

Properties	Type of wood	Value
Density	Dauglas fir (12% moisture)	0.46 – 0.50 g/cm^3
	Red Oak (12% moisture)	0.61 – 0.67 g/cm^3
Modulus of Elasticity	Dauglas fir (12% moisture)	10.8 - 13.6 GPa (parallel to grain) 0.54 – 0.68 GPa (perpendicular to grain)
	Red Oak (12% moisture)	11.0 – 14.1 GPa (parallel to grain) 0.55 – 0.71 GPa (perpendicular to grain)
Tensile Strength	Dauglas fir (12% moisture)	108 MPa (parallel to grain) 2.4 MPa (perpendicular to grain)
	Red Oak (12% moisture)	112 MPa (parallel to grain) 7.2 MPa (perpendicular to grain)

1.1.3 Maleic anhydride polypropylene (MAPP)

The MAPP used was DuPont™ Fusabond® P613. The resin from Fusabond® product are modified polymers that have been designed (typically by maleic anhydride grafting) to help bonding two different polymers or non-polymer used in strengthened, filled and combined compounds.

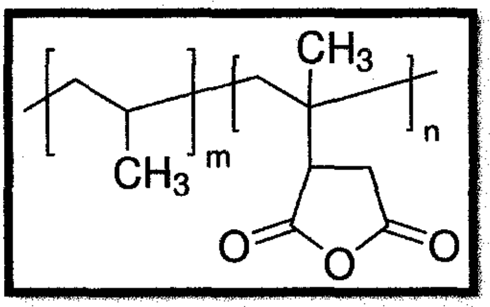


Figure 1.1: Molecular chain of MAPP [8].

As shown in the Figure 1.1, MAPP is the chemically combined or grafting of maleic anhydride on the backbone of PP polymer chain. The purpose of MAPP is as coupling agent to enhance the bonding between wood flour particles that are hydrophilic to be merged or embedded into PP matrix that are hydrophobic.

Table 1.4: Properties of MAPP [9].

Properties	Value	Standard
Density	0.903 g/cm³	ASTM D792
Melt Flow Rate (190°C/1.0kg, measured value)	49 g/10 min	ASTM D1238
Melt Index (190°C/2.16kg, estimated value)	120 g/10 min	ASTM D1238
Melting Point (DSC)	162°C	ASTM D4318
Maximum Processing Temperature	300°C	

1.2 PROBLEM STATEMENT

1.2.1 Problem Identification

Global warming has not only causes the melting of the iceberg in north and south poles, but it is threatening our existence as human on this planet. This issue has never depleted but keep on being raised until today. The prime cause of global warming is of course the greenhouse effect due to high concentration of CO_2 in our atmosphere that traps the heat and radiation from the sun. Hence, as everybody knows that the one and only natural absorbent of CO_2 is the forest and plants. Therefore, we need to save the earth by minimizing the urge to cut the trees and keep recycling any recyclable resources that we have around us and not using plastic bag anymore.

Therefore, plastic-wood composites has been researched and used since previous decade. However, most of the composites used were virgin polymer resin. Most of the plastic takes more than 500 years to degrade by itself [10]. Thus, recycling the recyclable plastics into another useful product would be a wise choice in order to save the earth.

Though, the tensile strength, flexural strength, and the microstructure of the r-PP/WF are not well understood and the sustainability towards the environment of the r-PP/WF composites is also unknown, and need to be discovered in this project.

1.2.2 Significance of Project

Recycled PP/WF composite is one of the potential alternative materials to replace solid wood products, for instance, furniture, decks, pergola and etc. Due to the special properties of polypropylene, it has better properties than HDPE in term of working temperatures and tensile strength, and the melting point is below the flash point of wood flour. From the results of this project, other researcher in the future can use this project as their basis for further study in this area and also reference in designing something using this type of composite. The most important impact is, by discovering and proving that this composite can replace the solid wood product as well as virgin PP products, we can help saving the environment by minimizing the usage of virgin PP and wood.

1.3 OBJECTIVES

The objectives of this project are:

1. To study the effects of r-PP/WF composites on mechanical properties.
2. To study the effects of coupling agent on the mechanical properties of the composite.

1.4 SCOPE OF STUDY

This study is mainly focus on producing the composition ratio of r-PP/WF that will produce the best mechanical properties. MAPP was used as the coupling agent to enhance the adhesion between hydrophobic matrices(r-PP) with hydrophilic reinforcement (WF). The mechanical testing involved were tensile test (ASTM D638), flexural test (ASTM D790) and Izod impact test (ASTM D256). The microstructures of the composites were analyzed using SEM to explain the mechanical properties behavior.

1.5 RELEVANCY OF PROJECT

The results from this study will contribute a lot of information for future improvement. By proving the tensile and flexural properties of the r-PP/WF composite are better than solid wood and virgin PP, we can use this composite as alternative material to replace wood products in the furniture industry, automotive industry, and architecture industry.
Besides that, we can recycle the PP product and also reuse the WF as the reinforcement of the polypropylene. Therefore, the demand and usage of virgin PP will be reduced.

In addition, this project is directly relevant with the knowledge that had been gained throughout 4 years of study in Mechanical Engineering Program. For instance, study in material (PP), mechanical testing (tensile and flexural), and Manufacturing Technology (compression molding).

Figure 1.2 shows outdoor decking or balcony made of WPC. This shows that this study is relevant to the current market and the study of WPC has been done around the world for at least 50 years. However, the study on r-PP and WF has not been done widely.

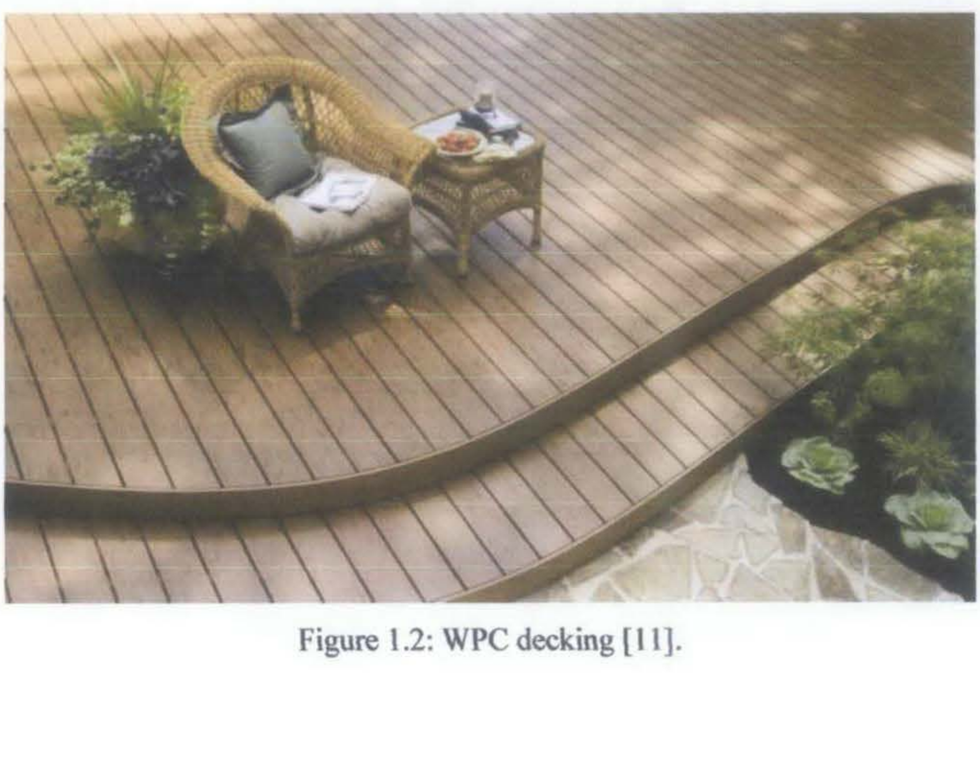


Figure 1.2: WPC decking [11].

1.6 FEASIBILITY OF PROJECT

The project is mainly depending on the availability of the machines required to prepare the specimen, which are granulator machine, oven to dry the WF, twin screw extruder and compression molding machine. For the study of the products properties, the Universal Testing Machine will be needed and the SEM machine for microstructure analysis. All of the machines needed are available in UTP laboratories.

In addition, both r-PP and WF are waste materials from the local industries. Therefore, it does not require a lot of money to get the material. Definitely, the cost for this project is within RM500 that had been allocated for FYP.

By referring to the Gantt chart, Project Activities and Key Milestone in the next chapter, if there is no technical problem with the machines, all of the experiments and testing will be able to be done within the time given. In conclusion, this project is feasible to be done within the time frame and the budget given.

CHAPTER 2
LITERATURE REVIEW

2.1 WOOD PLASTIC COMPOSITES OVERVIEW

Wood Plastic Composites (WPC) is not a new research because it has been used in the industries since 50 years ago. In recent decade, WPC attracted great interest among researchers', also polymer and wood industry. Most of the early industrial applications of wood filled polymers used in thermosetting resin systems such as phenol-formaldehyde resins. Industrial applications of lignocellulose filled thermoplastics were reported in the late 1960s [12]. Therefore, this technology is not new in United States, but in Malaysia, the market of WPC is still new. It is probably because Malaysia still rich with virgin forest that hold vast amount of woods.

Most of the researches done on WPC, especially on PP/WF were done in order to find the best method to produce better composite. Some of the positive attributes of wood filled plastic composite lumber compared to wood include its durability, low maintenance, no painting, insect and decay resistance, and it will not warp, splinter, and crack. Besides that, PP/WF is denser, thus it holds screws better and can be manufactured to be resistant to ultraviolet light, by adding some modifier or coupling agent [13].

The reinforcement used in the WPC, normally cellulose natural fiber such as sawdust, rice husk, palm fiber, and coconut fiber. The filler is the main element that will affect the properties of the composites because its purpose is to act as reinforcement in the composite. A research had been done by Nicole Stark [14] in 1997, which investigating the effect of species and particle size of the WF on the properties of WPC. From the research, it is certain that the particle size of the wood flour and the type of the wood flour affected the properties of the composite significantly.

Polymers are hydrophobic or non-polar substances that are not compatible with hydrophilic substances because, on the other hand, wood flour is polar. Therefore, this polar-non-polar relation will cause poor adhesion between polymer and wood flour in the composites. To overcome that problem, coupling agent such as MAPP is used to make the bonding between the natural fiber reinforcement (wood flour) and the polymer matrix (PP) stronger. Besides that, ethylene/propylene/diene terpolymers (EPDM) and maleated styrene-ethylene/butylene-styrene triblock co-polymer (SEBS-MA) also been used as impact modifiers in the PP/WF composites [15].

In addition to that, the filler or natural fiber also can be modified to enhance the contact or bonding between the polymer and fiber. One example of filler treatment is using acid by soaking the wood flour in monochloroacetic acid for few hours. In other research, they are using alkali treatment by soaking the wood flour in sodium hydroxide and vinil-tris-(2-metoxietoxi)-silane [16].

2.2 Benefits of Wood Plastic Composites

First of all, the purpose of producing WPC products is to minimize the usage of virgin polymer (i.e Polypropylene) or solid wood. Subsequently, this can preserve redwood, cedar and other hardwoods species. Also, the WPC products are low or relatively no maintenance unlike solid wood which need to be re-paint, replace, repair and waxing. The WPC products are good for exterior purposes, without worrying about the rain or hot day since the products are water proof and termite-free. Since it is a composite of wood and polymer, the appearance still looks like solid wood, but lighter. Indeed, more durable if compared to solid wood.

In economical view, WPC has open up another opportunity for both small and large scale business with relatively small initial capital. This is due to the changes in perspective of some plastics industries in the last decade. Interest has been fueled by the success of several WPC products, greater awareness and understanding of wood, developments from equipment manufacturers and additive suppliers, and opportunities to enter new markets, particularly in the large-volume building applications sector [17].

2.3 WOOD PLASTIC COMPOSITES PREPARATION

Even though every researches have their own purpose and hypothesis, but the main methodology used to produce the composites are mostly the same. They only vary in term of the treatments done on the wood flour, type of reinforcement, the coupling agents, stabilizers, ratio and composition of the composites used in the research.

The procedures are started with pre-heating the wood flour or sawdust to eliminate the moisture until the moisture contains approximately less than 1%. While, the PP is prepared in powder, flakes form, granulated form or pelletized form. Then, the PP and WF will be pre-mixed before proceed into the co-rotating twin screw extruder and finally using compression molding machine to produce the samples for mechanical testing purposes according to the standards used (ASTM D638, ASTM D790, ASTM D256) [18].

In order to produce good composites, a lot of aspects need to be considered in choosing the right polymer and the reinforcement. Due to the limited thermal stability of wood, only thermoplastics that melt or can be processed at temperatures below 200°C are commonly used in WPCs [19]. Therefore, the typical thermoplastic polymers used in WPC processing are HDPE, LDPE, PP and some PVC.

Usually, the composites contain approximately 50% wood, although some composites contain very little wood and others as much as 70% and the typical particle sizes of the woof flour are range from 10 to 80 mesh (2000 microns – 177 microns) [17]. Some uses wood flour (typically 40 mesh or lower) or recycled paper fiber. Wood contents normally range from 20 - 60% in these composites [13].

2.4 FINDINGS FROM THE RESEARCHES

In the research of the effect of coupling agents on PP/WF properties, it is found that the addition of MAPP, maleated EPDM and SEBS increased the impact strength of the PP/WF composites but the addition of maleated EPDM and SEBS gave the greatest improvements in impact strength. Addition of MAPP did not affect the impact properties of the composites but had a positive effect on the composite unnotched impact strength when used together with elastomers.

Tensile tests showed that MAPP had a negative effect on the elongation at break and a positive effect on tensile strength. The impact modifiers were found to decrease the stiffness of the composites. Scanning electron microscopy showed that maleated EPDM and SEBS had a stronger affinity for the wood surfaces than did the unmodified EPDM. The maleated elastomers are, therefore, expected to form a flexible interphase around the wood particles giving the composites better impact strength. MAPP further enhanced adhesion between WF and impact-modified PP systems. EPDM and EPDM-MA rubber domains were homogeneously dispersed in the PP matrix the diameter of domains being between 0.1 – 1.0 μm [16].

All treatment shows slightly increases in tensile modulus and tensile strength of the composites, but the MFI did not affected. Morphological study shows that MAPP and silane improve PP-WF adhesion and dispersion of particles [12]. Besides the coupling agent, the species and particle size of the reinforcement also important in improving the properties of PP/WF composite properties.

It was proven by Nicole Stark [14] that, with increasing wood flour content, melt index decreased, mold shrinkage decreased, notched impact energy increased while unnotched decreased, flexural and tensile strength decreased, while modulus of elasticity increased, and tensile percentage elongation decreased. The hardwoods exhibited slightly higher values for flexural and tensile strength and modulus, higher heat deflection temperature, and lower percentage tensile elongation than did the softwoods. And lastly, the specific gravity was species independent [15].

CHAPTER 3

METHODOLOGY

3.1 RESEARCH METHODOLOGY

1. Studies on the r-PP/WF preparation processes

a) Literature review on r-PP/WF composites

2. Recycled PP and WF preparation

a) Collect and cut PP products into small pieces

b) Using Granulator machine to make flakes recycled PP

c) Using siever to get the 425 microns wood flour

d) Using oven to dry the WF at 75°C for 48 hours

3. Composite PP-WF preparation

a) Extrude PP+WF

b) Compression Molding (set temp. 190°C at 50 bar)

4. Properties Testing

a) Tensile Test

b) Flexural Test (3-point bending)

c) Izod Impact Test

5. Microstructural Testing

a) SEM (300x - 500x magnification)

6. Discussion/ Analysis

a) Data comparison

b) Interpretation

c) Limitation

d) Recommendation

7. Conclusion

Figure 3.1: Research Methodology.

3.1.1 Sample Preparation

Table 3.1 shows the amount of materials used in this project. About 4 kg of food container made from PP collected, cleaned, dried, cut into small pieces and granulated into flakes form. 1.4 kg of wood flour was sieved and dried and 100 g of MAPP Dupont™ Fusabond® P613.

Table 3.1: Typical mount of materials used.

Material	r-PP	WF	MAPP
Mass (kg)	5	1.4	0.1

1. Recycled Polypropylene preparation

Food containers made from Polypropylene which is recyclable and have number '5' as resin identification code, as shown in Figure 3.2.

Figure 3.2: PP resin identification code.

Figure 3.3: Polypropylene recycling processes.

Figure 3.3 shows the process of recycling PP from food container. Firstly, the picture on the left taken after food containers are collected, cleaned, and dried at room temperature. Secondly, the middle picture shows PP food containers cut into smaller pieces. Lastly, the picture on the right shows r-PP in flakes form after granulated using granulator machine.

2. Recycled Wood Flour preparation

The wood flour were collected from a hoe factory that uses *Belian* wood as the hoe's handle.

Figure 3.4: Wood flour preparation processes.

Figure 3.4 shows the preparation in order to get the desired particle size of wood flour and having less than 1% moisture content. The picture on the left is the wood flour before being sieved and the picture on the right is the wood flour after being sieved 425 microns and dried in the oven at 75°C for 48 hours. The texture of the dried wood flour are slightly different and more brownish if compared to the original colour of the wood which is reddish-brown.

3. Maleic Anhydride grafted Polypropylene

The Figure 3.5 shows the picture of MAPP resin from Dupont™ Fusabond® P613. The colour is crystal clear, but the smell is irritating.

Figure 3.5: MAPP from Dupont™ Fusabond® P613.

Table 3.2: Compositions of the specimens in wt%.

Sample	PP(%)	WF(%)	MAPP (%)
A	100	0	0
C	70	30	0
D	60	40	0
E	50	50	0
G	65	30	5
H	55	40	5
I	45	50	5

4. Mixing and compounding using co-rotating twin screw extruder machine

Using twin screw extruder:

a. Based on the compositions, the extrusion process started with Sample A, C and G, D and H, lastly E and I. This means from 0% of wood until 50% of wood, and started the sample without coupling agent.

b. Temperature profile for all compositions:
   - Zone 1 & 2 : 185°C
   - Zone 3 – 7 : 170°C
   - Die : 170°C

c. Screw speed : 50 rpm

d. The composite string dried at room temperature (~25°C), without water quenching to minimize moisture contact with the samples.

e. Then, the strings were cut using the pelletizer machine (2 – 4 mm length).

f. The pellets will be kept in the oven at 75°C for another 48 hours to remove the moisture before proceed with injection molding to avoid bubbles in the samples.

Figure 3.6 shows the samples after compounded using extrusion machine. The most left picture is Sample C (70/30 r-PP/WF) followed by Sample D (60/40 r-PP/WF) and most right picture is Sample E (50/50 r-PP/WF).

Figure 3.6: Samples after extrusion process.

Table 3.3 shown the code and standards were used in this project.

Table 3.3: Code & Standard.

Activity	**Code & Standard**
Tensile Testing	ASTM D638
Flexural Testing	ASTM D790
Izod Impact Testing	ASTM D256

5. Compression Molding to produce testing samples

a. The temperature profile: 190°C at 5 MPa.

b. Average cycle time: 5 minutes and 30 seconds.

Figure 3.7 shows the flash-type mold or picture frame mold that made of metal and sandwiched between two thin metal ferrotype plates.

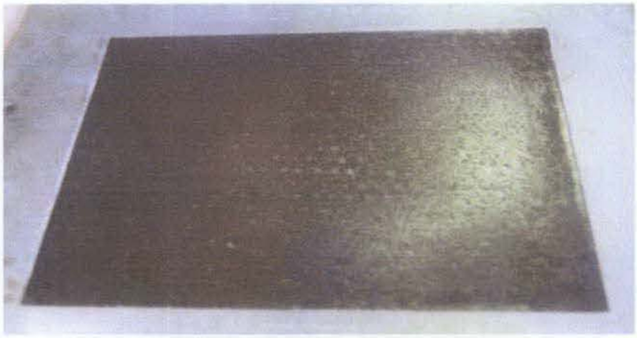


Figure 3.7: Flash-type mold.

Compression molding simplified procedure:

1. Pellets of the composite were poured into the mold, and add extra approximately 10 g in the middle.
2. The mold must be layered with a thin sheet of Teflon on both sides of the mold.
3. The mold was put carefully on the platen, turn the switch to 'heating' mode, and press both 'green' start buttons.
4. The machine will automatically preheat, press, and mold the sample in 5 minutes and 30 seconds.
5. When the time is up, the machine will automatically open both platens so the mold can be moved into the lower platens for cooling under pressure.
6. Turn the switch to 'cooling' mode, and press both 'green' start buttons to initiate the cooling process.
7. After 5 minutes and 30 seconds, using the hard leather gloves to take out the mold and pull the sample plate.
8. The sample plate will be further cooled until room temperature and put in zipper bag to keep it from moisture.
9. Then, the samples were cut into tensile, flexural and impact testing specimens.

Figure 3.8: Compression molding machine.

Figure 3.8 shows the compression molding machine located at PRSB. LAB TECH Engineering Company Ltd. is the brand of the machine.

3.1.2 Mechanical Testing

a) Thermoplastic Tensile Testing [21]

(a) (b)

Figure 3.9: (a) INSTRON 5565 5 kN Universal Testing Machine.

(b) Broken sample after tensile test.

Figure 3.9 shows the Universal Testing Machine and the tensile test in progress.

Using ASTM D638 tensile test standard:

1. Load the specimen into the tensile grips.
2. Open INSTRON SERIES IX software and set up all the parameters needed in the computer sync with the machine.
3. Click START to begin the test by separating the tensile grips at a constant cross head speed of 50 mm per minute.
4. Wait for few minutes until the sample breaks.
5. Once the sample breaks, click END to stop the recording.

b) Thermoplastic Flexural Testing [24]

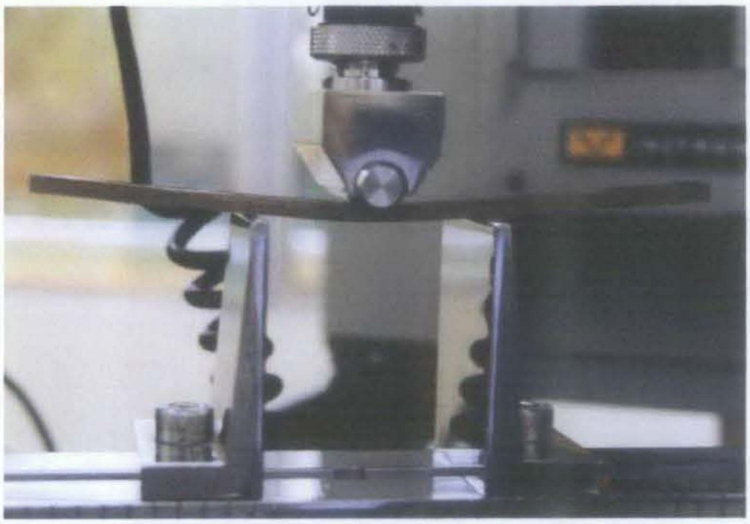


Figure 3.10: Three-point Bending Flexural testing.

Figure 3.10 shows the sample being tested for flexural test or 3-point bending test.

Using ASTM D790 flexural test standard:

1. Put the specimen on the supports and make sure the middle span is 50mm.
2. Open INSTRON SERIES IX software and set up all the parameters needed in the computer sync with the machine.
3. Click START to begin the test by loading the nose in the middle of the span at a constant cross head speed of 2 mm per minute.
4. Wait for few minutes until the sample breaks. (The test is stopped when the specimen reaches 5% deflection or the specimen breaks before 5%)
5. Once the sample breaks, click END to stop the recording.

Figure 3.11: Bended or broken flexural specimen.

Figure 3.11 shows the broken sample after being tested with flexural test. Due to its brittleness, the sample breaks before 5% of the deflection.

c) Plastics Izod Impact Testing for ASTM D256 [26]

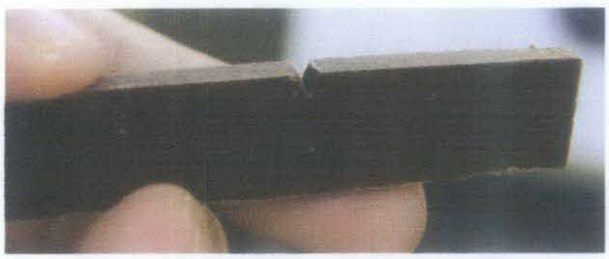
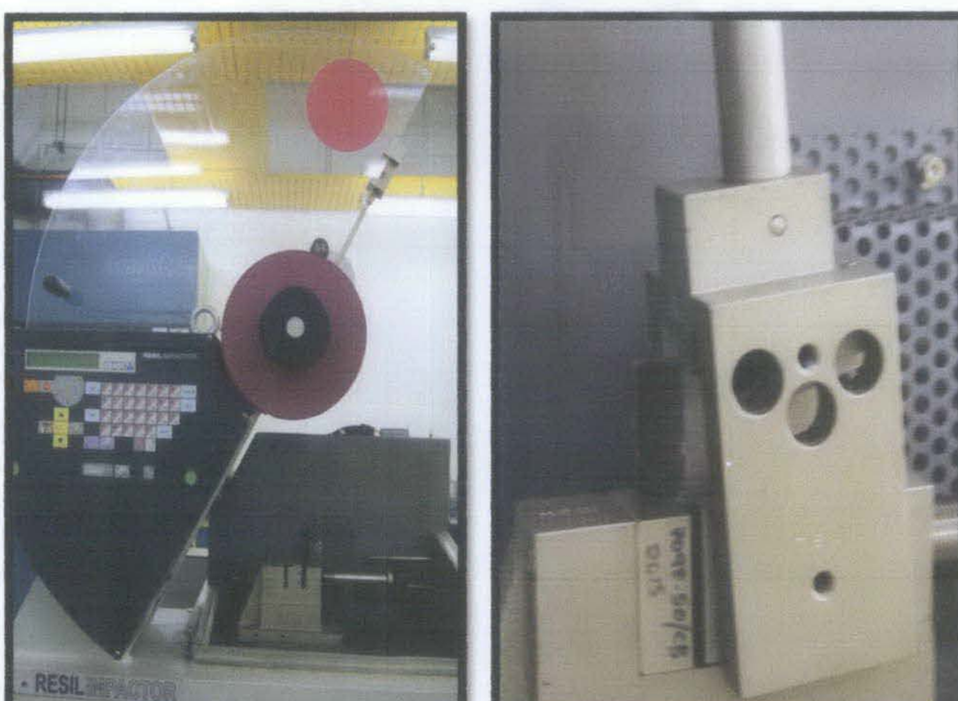


Figure 3.12: Notched specimen



(a) (b)

Figure 3.13: (a) Izod impact test machine or known as Resil Impactor.

(b) The specimen during the impact process.

Before performing the Izod impact test, the specimens must be notched as shown in Figure 3.12. Figure 3.13 shows the Izod impact machine and the Izod impact test technique.

Using ASTM D256 Izod impact test standard:

1. The specimen is clamped into the pendulum impact test fixture (10 N clamping forces) with the notched side facing the striking edge of the pendulum.
2. The pendulum is released and allowed to strike through the specimen.
3. The data throughout the testing was collected automatically by the machine and synchronized with the computer next to it.
4. Overall 6 specimens were tested for each sample composition.

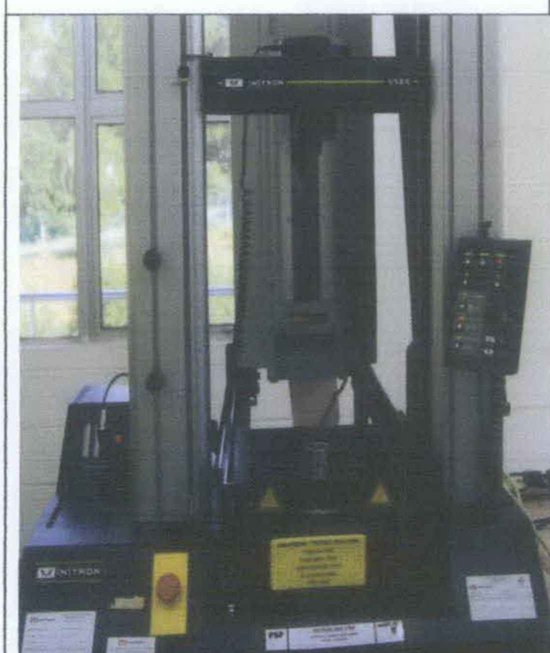
3.2 TOOLS AND EQUIPMENTS REQUIRED

Table 3.4: Tools and Equipment

Tools and Equipment		
 Oven	 Siever machine	 Scanning Electron Microscope (SEM)
 Co-rotating Twin Screw Extruder		

Compression Molding Machine

Granulator Machine



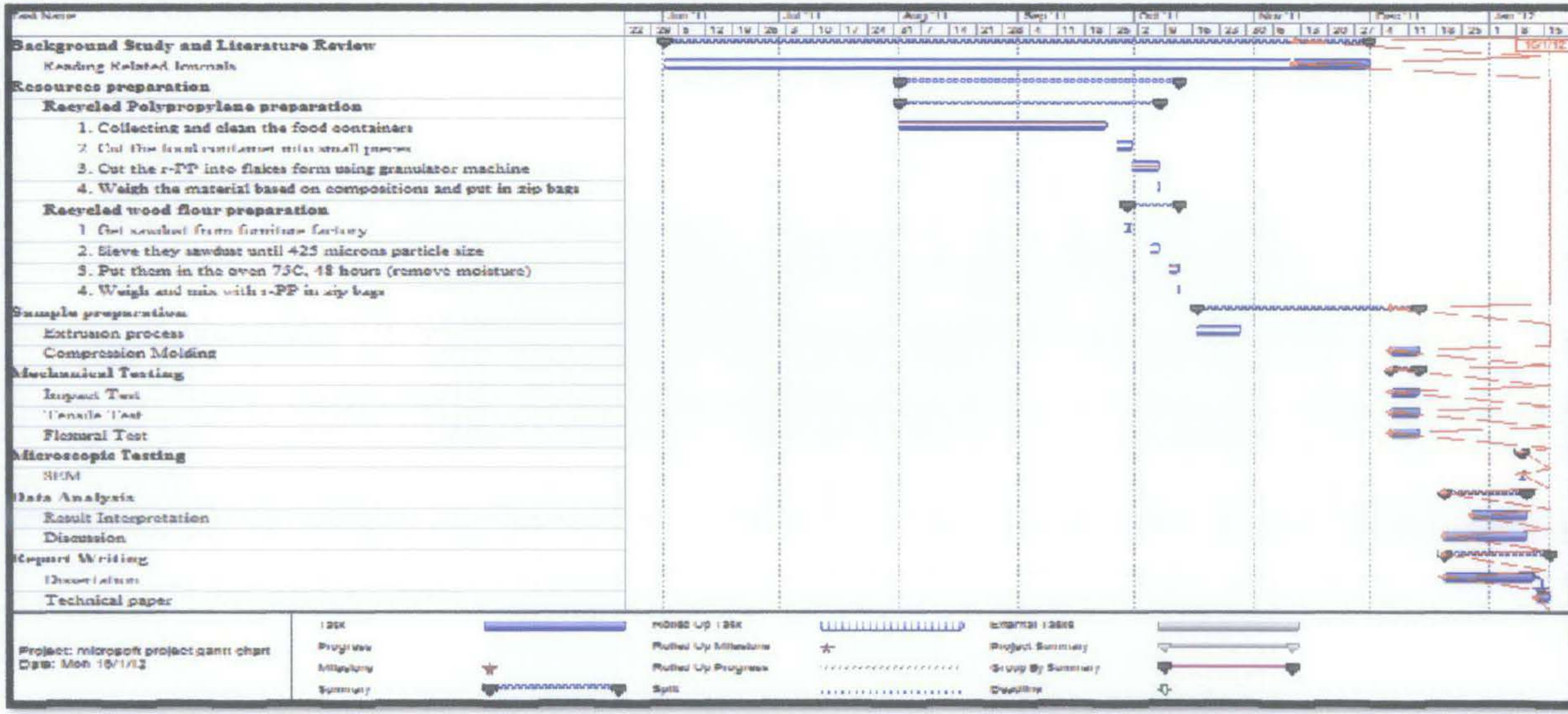
Universal Tensile Machine

Izod Impact Test

Table 3.4 shows all the equipment used throughout this project from material preparation up to mechanical testing and microstructure study.

3.3 PROJECT ACTIVITIES, GANTT CHART AND KEY MILESTONE

Table 3.5: Gantt chart



CHAPTER 4
RESULTS AND DISCUSSIONS

This chapter will show all the findings obtained from Tensile Test, Flexural Test, and Izod Impact Test. To support and understand the mechanical behavior, SEM analysis was done for 4 samples which are 70/30, 50/50, 65/30/5 and 45/50/5 compositions. The comparison of microstructure with and without coupling agent composites also analyzed.

4.1 TENSILE STRENGTH

The tensile test was performed using an INSTRON 5565 UTM 5kN machine located at PRSB. The crosshead speed for the test was 50 mm/min, temperature of 23°C and 50% humidity. Table 4.1 shows good value of r-PP tensile strength proved that the tensile test is done accordingly to ASTM D638 standard. It might be slightly different if compared to virgin PP value due to recycle treatment. Table 4.1 below shows the average tensile strength of the r-PP and r-PP/WF composites.

Table 4.1: Average tensile strength of the composites.

Samples	Tensile Strength (MPa)						
	r-PP	**70/30**	**60/40**	**50/50**	**65/30/5**	**55/40/5**	**45/50/5**
1	26.21	22.23	18.76	14.80	23.79	23.03	24.25
2	29.94	21.25	17.32	15.15	27.79	24.65	16.01
3	29.98	20.19	17.29	14.55	23.33	25.90	18.18
4	29.23	21.67	18.14	15.16	23.26	21.50	18.76
5	27.83	20.41	16.25	13.60	24.01	21.76	23.87
Average	**28.64**	**21.15**	**17.55**	**14.65**	**24.44**	**23.37**	**20.21**
Standard Deviation	**1.61**	**0.85**	**0.95**	**0.64**	**1.90**	**1.89**	**3.66**

From this result, by calculating of the values gathered, MAPP has significantly improved the tensile properties of the composite. For 30% WF, MAPP improve the strength 15.5%, while for 40% WF, MAPP improve the strength up to 33.2% and for 50% WF, MAPP enhance the strength up to 38.2%.

The bar chart shown in Figure 4.1 shows the comparison of different WF percentage and existence of MAPP on the tensile strength of the composites. For each sample, 5 specimens were tested and the standard deviation is shown by the error bar. From this bar chart, the improvement done by adding MAPP into the composite can be clearly seen. However, the tensile strength of the composite decreases when the percentage of WF increase. As a conclusion, the strongest composition with respect to tensile strength is Sample G with ratio 70/25/5 weight percentage of r-PP/WF/MAPP.

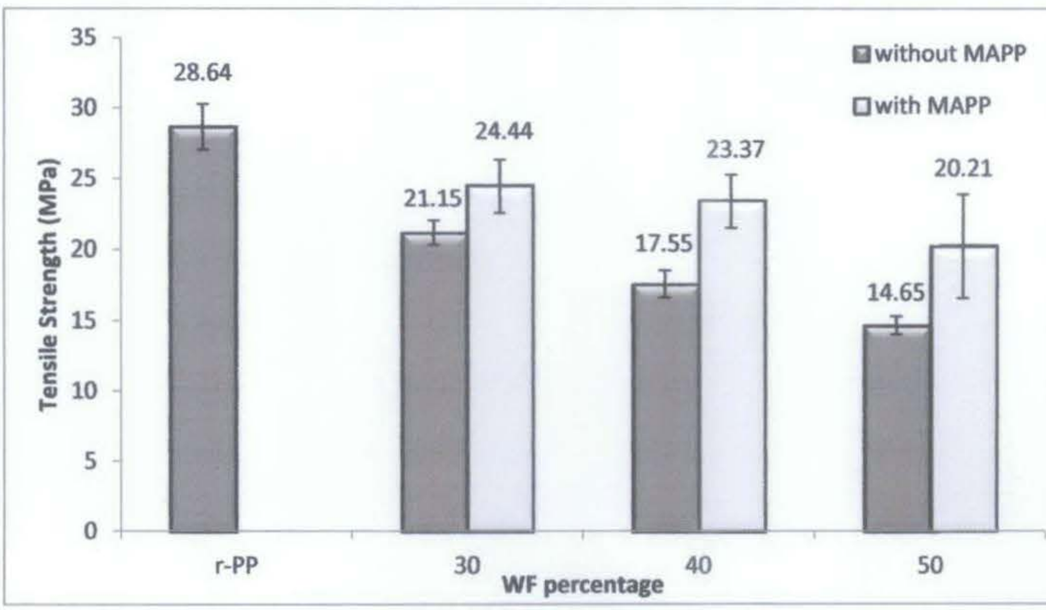


Figure 4.1: The effects of WF percentage and MAPP on tensile strength.

4.2 FLEXURAL PROPERTIES

The flexural test was also performed using an INSTRON 5565 UTM 5kN machine located at PRSB. The crosshead speed for the test is 2 mm/min, temperature of 23°C and 50% humidity. Table 4.2 shows good value of r-PP flexural strength proved that the flexural test is done accordingly to ASTM D790 standard. It might be slightly different if compared to virgin PP value due to recycle treatment. Table 4.2 below shows the average flexural strength of the r-PP and r-PP/WF composites.

The bar chart shown in Figure 4.2 shows the comparison of different WF percentage and existence of MAPP on the flexural strength of the composites. For each sample, 5 specimens were tested and the standard deviation is shown by the error bar. From this bar chart, the improvement done by adding MAPP into the composite can be clearly seen. However, the flexural strength of the composite also decreases when the percentage of WF increase. The strongest composition with respect to flexural strength is also Sample G with ratio 70/25/5 weight percentage of r-PP/WF/MAPP.

Table 4.2: Average flexural strength of the composites.

Samples	**Flexural strength (MPa)**						
	r-PP	**70/30**	**60/40**	**50/50**	**65/30/5**	**55/40/5**	**45/50/5**
1	43.54	30.77	26.04	23.91	45.09	37.91	33.29
2	48.20	27.78	28.57	24.06	44.13	36.10	32.17
3	38.15	28.79	25.02	24.20	36.10	43.22	31.05
4	44.49	25.00	27.63	24.86	43.17	39.58	29.26
5	44.80	28.08	28.00	24.11	39.80	41.27	30.16
Average	**43.84**	**28.08**	**27.05**	**24.23**	**41.66**	**39.62**	**31.19**
Standard Deviation	**3.63**	**2.08**	**1.47**	**0.37**	**3.69**	**2.78**	**1.59**

From calculation of the increment percentage, MAPP has significantly improved the flexural properties of the composite. For 30% WF, MAPP improve the strength 48.4%, while for 40% WF, MAPP improve the strength up to 46.5% and 50% WF, MAPP enhance the strength only 28.7%.

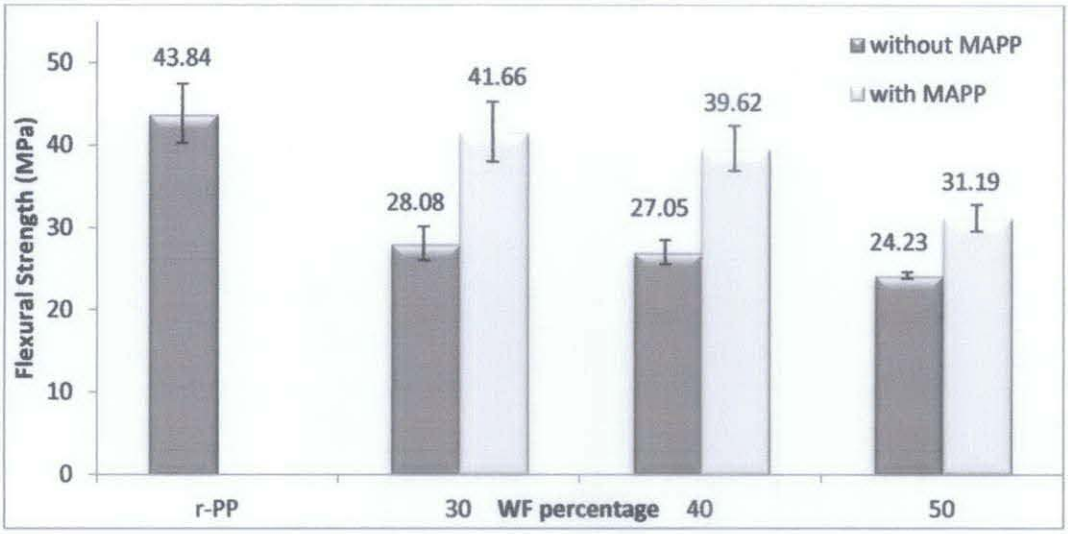


Figure 4.2: The effects of WF percentage and MAPP on flexural strength.

From the flexural testing experiment, flexural modulus was also calculated automatically by the machine and sync with the computer. Table 4.3 shows the average flexural modulus of the composites.

Table 4.3: Average flexural modulus of the composites.

Samples	**Flexural modulus (GPa)**						
	r-PP	**70/30**	**60/40**	**50/50**	**65/30/5**	**55/40/5**	**45/50/5**
1	1.27	1.50	1.70	2.52	2.56	2.34	3.11
2	1.44	1.43	2.52	2.33	2.89	2.45	3.29
3	1.29	1.39	1.91	2.25	2.41	2.85	3.13
4	1.33	1.47	1.63	2.53	2.51	2.82	3.10
5	1.39	1.48	2.31	2.44	2.70	2.35	3.15
Average	1.34	1.45	2.01	2.41	2.61	2.56	3.16
Standard Deviation	0.07	0.04	0.39	0.12	0.19	0.25	0.08

From calculation of the increment percentage, MAPP also has significantly improved the flexural modulus of the composite. For 30% WF, MAPP improve the modulus up to 80%, while for 40% WF, MAPP improve the flexural modulus only 27.4% and 50% WF, MAPP enhance the modulus about 31.1%.

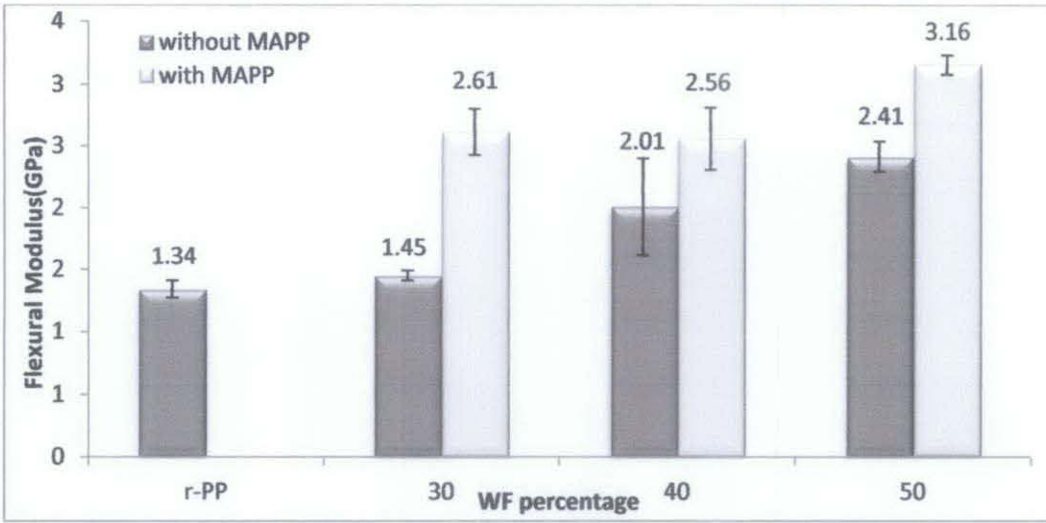


Figure 4.3: The effects of WF percentage and MAPP on flexural modulus.

The bar chart shown in Figure 4.3 shows the comparison of different WF percentage and existence of MAPP on the flexural modulus of the composites. The result was obtained from the same experiment as flexural strength. From this bar chart, the improvement done by adding MAPP into the composite can be clearly seen and the trend is increasing as the percentage of WF is increase. The strongest composition with respect to flexural strength is Sample I with ratio 50/45/5 weight percentage of r-PP/WF/MAPP.

4.3 IZOD IMPACT STRENGTH

The Izod impact test was performed using a CEAST® Resil Impactor machine located at PRSB. The impact energy imposed 7.5 J, impact velocity 3.46 m/s, impact angle 150 degrees and the clamping force 10 N. Table 4.4 shows good value of r-PP tensile strength proved that the tensile test is done accordingly to ASTM D256 standard. It might be slightly different if compared to virgin PP value due to recycle treatment. Table 4.4 shows the average impact strength of the r-PP and r-PP/WF composites.

From calculation of the increment percentage, MAPP has slightly improved the impact strength of the composite. For 30% WF, MAPP improve the impact strength 3.1%, while for 40% WF, MAPP improve the impact strength for13.1% and 50% WF, MAPP enhance the strength about 5.5%.

Table 4.4: Average impact strength of the composites.

Samples	Impact strength (kJ/m²)						
	r-PP	70/30	60/40	50/50	65/30/5	55/40/5	45/50/5
1	3.12	2.12	2.03	2.39	2.00	2.36	2.40
2	2.58	1.75	2.01	2.21	2.00	2.42	2.24
3	3.75	2.04	2.19	2.13	2.09	2.56	2.35
4	3.00	1.88	1.86	2.15	1.90	2.20	2.29
5	3.04	1.88	1.80	2.02	1.97	1.68	2.20
Average	**3.10**	**1.93**	**1.98**	**2.18**	**1.99**	**2.24**	**2.30**
Standard Deviation	**0.42**	**0.14**	**0.15**	**0.14**	**0.07**	**0.34**	**0.08**

The bar chart shown in Figure 4.4 shows the comparison of different WF percentage and existence of MAPP on the impact strength of the composites. For impact test, 6 notched specimens were tested. From this bar chart, the improvement done by adding MAPP into the composite can be seen and the trend is slightly increasing as the percentage of WF is increase. The strongest composition with respect to flexural strength is Sample I with ratio 50/45/5 weight percentage of r-PP/WF/MAPP.

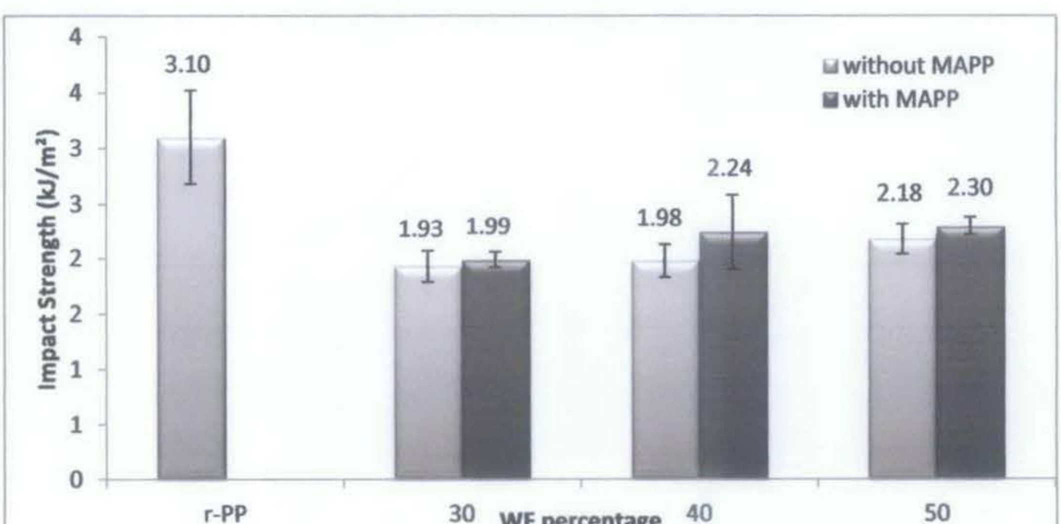


Figure 4.4: The effects of WF percentage and MAPP on impact strength.

Based on the results obtained from mechanical testing, all of the composites show lower properties than r-PP. One of the reasons why all of the composites have lower properties is because of the voids that trapped in the composites. During processing and sample preparation, a lot of voids in the composites can be observed by naked eyes. These voids mostly happened in lower WF weight percentage contain. It is not caused by moisture, but it happened due to the different sizes of pellets and the WF is not uniformly distributed.

When this occurs, during compression molding, smaller pellet will easier to melt if compared to larger or longer pellets. When it being compressed, there are voids of air trapped in between the pellets. And when the plates were cut, the voids can be seen clearly. That is why the sample of 80/20 r-PP/WF and 75/20/5 r-PP/WF/MAPP are not included in the results because of too many voids.

Figure 4.5: Visible voids in composite plate.

Figure 4.5 shows the voids in composite plate that can be seen clearly. Figure 4.6 shows a big void captured under SEM. This is one of the factors that reduce the composites mechanical properties.

Figure 4.6: Void in composite taken using SEM

However, besides the weakness, MAPP has proven to improve the composites mechanical properties. Theoretically, MAPP is a coupling agent which enhances the adhesion between a hydrophobic r-PP with hydrophilic WF. So, in other word, MAPP will act as glue between the barrier of r-PP and WF. By looking at Figure 4.7, that is the microstructure of composite without coupling agent after 1000x magnifications. The boundary gap between r-PP and WF can clearly be seen. If compared to the composite with MAPP, shown by Figure 4.8, with the same magnifications and WF contain, there is no boundary gap between r-PP and WF. This explains clearly why the composites with MAPP show higher mechanical properties since there is bonding and better adhesion between r-PP/WF.

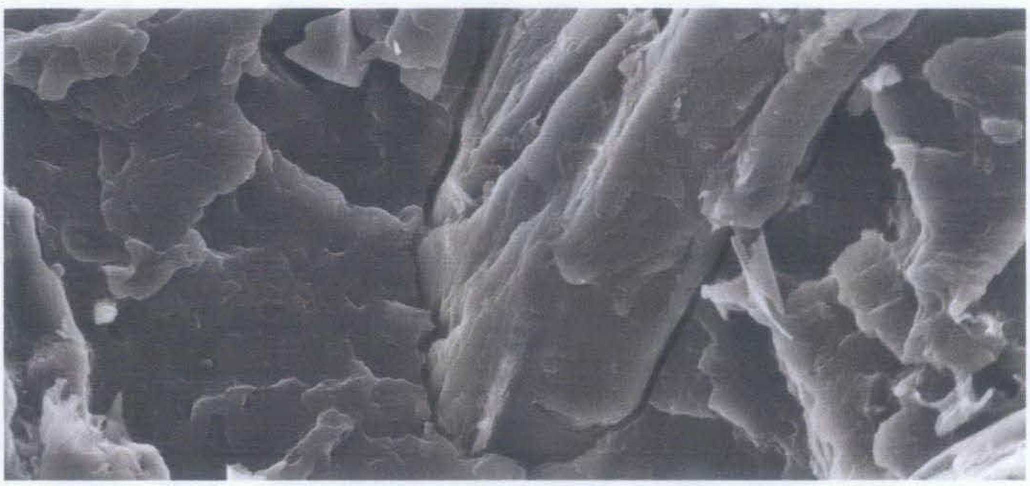


Figure 4.7: Composite microstructure without coupling agent

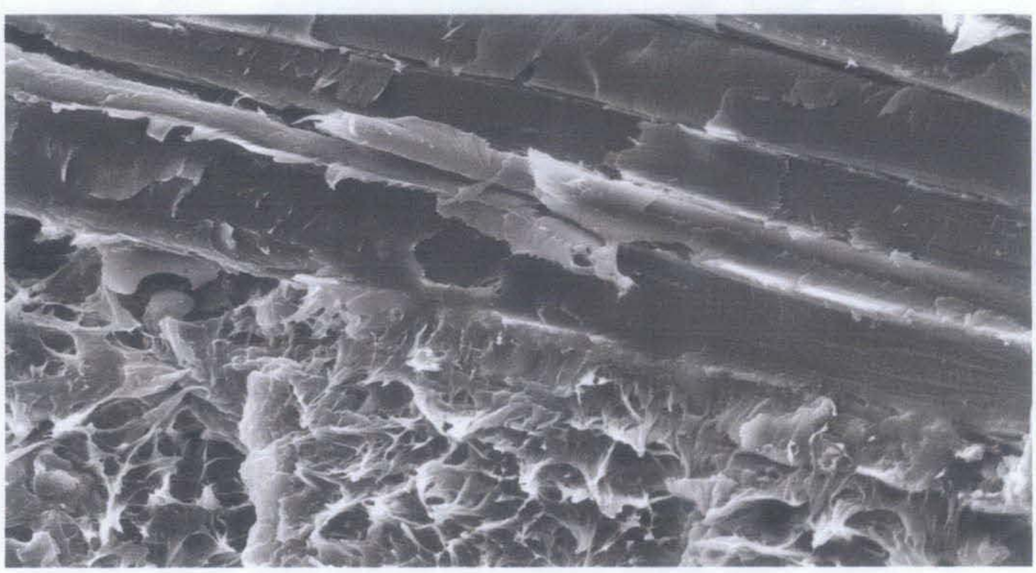


Figure 4.8: Composite microstructure with coupling agent

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

In conclusion, this project has satisfied both of the objectives. However, all of the composites either with or without coupling have lower mechanical properties if compared to neat r-PP, except for flexural modulus. Fortunately, MAPP has improved the mechanical properties significantly for each testing. The composite that has the highest tensile strength is sample 65/30/5 r-PP/WF/MAPP with 24.44 MPa which is 14.7% different with neat r-PP. Also, for flexural strength, the 65/30/5 r-PP/WF/ MAPP composite shows the highest strength of 41.66 MPa which is 5.0% less than neat r-PP which is comparable. Yet, the flexural modulus shows great improvement and the composite that has the highest flexural modulus is 45/50/5 r-PP/WF/MAPP with 3.16 GPa. This means 135.8% improvement from neat r-PP. Lastly, the impact strength of the composites are much lower than neat r-PP, the highest impact strength is 45/50/5 r-PP/ WF/MAPP with 2.30 kJ/m^2 which is lower 25.8% than neat r-PP. Overall, the composites were expected to be stronger and tougher as the amount of WF increases. But due to the processing techniques and some error during sample preparation, the results are not as expected. Still, this project has proven that MAPP has successfully enhances the bonding between r-PP and WF which results in increased in all mechanical properties if compared to the composites without MAPP.

5.2 RECOMMENDATIONS

Based on the study, I am satisfied with the results obtained, there are a lot of things that can be improved for future studies. One of it is to add other type of modifier such as UV stabilizer to improve its durability upon sunlight. Besides that, use other method to enhance the adhesion between r-PP and WF. For instance, acid or alkali treatment can be done on the wood flour to disperse the wood particle. This can make more area for r-PP in between the particles. In term of processing, injection molding probably can produce better specimens for the testing. Thermal properties the composites and water absorption test also can be studied.

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