Tensile and Flexural Properties of HDPE/PET/Kenaf Hybrid Composites

By

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

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CERTIFICATION OF APPROVAL

Of Research Project

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

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SEPTEMBER 2012

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.

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ABSTRACT

Natural fiber reinforced plastics (NFRP) is one of the advanced technologies developed in the engineering material industry. The examples of NFRP are kenaf fiber reinforced polypropylene (PP) composites; pineapple leaf fiber reinforced high-density polyethylene (HDPE), and others. The advantages of NFRP are biodegradable, lightweight, low production cost and it does not release carbon dioxide when burnt. NFRP has been extensively used in manufacturing the interior parts of car and bumpers. Hybrid composite is defined as a matrix that bonds with two or more reinforcements. Theoretically, hybrid composites offer better mechanical properties than non-hybrid composites. This work aimed to the study of tensile and flexural properties of HDPE/ Polyethylene terephthalate (PET) fiber/kenaf hybrid composites with and without compatibilizer. Two equal weight proportions of fibers were fabricated using compression molding technique at processing temperature of $200^{o}C$. A compatibilizer was added to further enhance the interfacial bonding between fibers and matrix. The samples obtained were undergone tensile and flexural tests according to ASTM D638 and ASTM D790 respectively. The overall result showed that the hybrid composites had higher tensile and flexural properties with highest improvement recorded was 32% and 51% respectively compared to neat HDPE. It was also found that the optimal fibers content for achieving highest tensile properties was 20 wt%. For flexural strength, the optimal fibers content was 30%. FESEM images were used to characterize the microstructure of the hybrid composites.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND STUDY

Concerns about global warming and relying too much on fossil fuel that will eventually run out has lead to renewed interest in natural fibers. Reliance on fossil fuels can be reduced through the use of natural fibers in composite materials. Natural fibers offer a lot of advantages over glass fibers in terms of its biodegradability, availability, and ease of fabrication [1]. When natural fiber reinforced plastics are decomposed or combusted at the end of their life cycle, the carbon dioxide released by the fibers is the same as that absorbed during their growth [2]. Moreover, natural fibers are easily combustible materials whereas man-made fibers have low energy values and high ash content when burnt [3]. NFRP were introduced with the objective of yielding lighter composites coupled with lower costs compared to existing fiber glass reinforced polymer composites.

In this project, kenaf fiber mat and short PET fiber were used as reinforcements whereas HDPE was used as matrix to form a hybrid composite. Kenaf fiber lies under vegetable type of natural fiber and they are made up of inner woody core and an outer fibrous bark surrounding the core. The kenaf comprises of 35-40% bast fiber and 60-65% core fibers by weight of the kenaf's stalk. Nowadays, door panels, seat backs, headliners, dashboards and other interior parts are made from natural fibers reinforced polymer composites [4]. HDPE has greater toughness, superior mechanical strength, and high service temperature compared to lower density polyethylene (LDPE) [5].

1.1 PROBLEM STATEMENT

Theoretically, hybrid composites should result in better mechanical properties. The reason is hybrid composites have more reinforcements than composites. Those reinforcements will bind together and subsequently eliminates each other's defects. However, very limited studies were done on mechanical performance such as tensile and flexural properties of HDPE/PET/kenaf hybrid composites. Therefore, this project was carried out with the intention to explore further about the combination of HDPE/PET/kenaf as hybrid composites.

1.2 OBJECTIVE

The objective of this project is to study the tensile and flexural properties of HDPE/PET/kenaf hybrid composites with and without compatibilizer.

1.3 SCOPE OF STUDY

This project used a commercial type of HDPE as a matrix together with short PET fiber and kenaf mat as the reinforcements. Fusabond P 613 supplied by DuPont was used as a compatibilizer. Five samples for each fibers composition were prepared using compression molding technique.

CHAPTER 2

LITERATURE REVIEW

2.1 OVERVIEW

Fiber reinforced polymer composite is a composite material made of polymer matrix reinforced with fibers. The fibers are normally the reinforcements which provide strength to the composites while the matrix is usually polymer resin used to bind the reinforcements. The fibers can be divided into two categories, which are natural fibers and synthetic fibers. Polymer matrix can be either thermoset plastic or thermoplastic.

Synthetic fibers such as carbon and glass fibers are the widest reinforcements used in fiber reinforced polymer field mainly driven by their superior mechanical properties, low moisture absorption and lightweight compared to natural fibers. Although carbon and glass fibers posses superior mechanical properties, they have some serious drawbacks such as non-biodegradable, low melting temperature, high production cost and release enormous amount of carbon dioxide when burnt [6].

Over the years, scientist has discovered that asbestos may cause cancer. Since glass fiber and asbestos are both made of silicate fibers, the safety of glass fiber is also being called into questions as studies showed that it may cause similar toxicity as asbestos [7-9]. Glass fiber also has caused several symptoms including irritation of eyes, skin, nose, throat, hoarseness and cough [10]. These health issues can be solved by using natural fibers as it is environmental friendly and it does not cause any health issue.

The development of natural fiber reinforced polymer composites have been the subject of interest in past years [11-13]. The natural fibers have low production cost, biodegradable, non-abrasive, and available in abundance amount compared to glass fibers [14]. Natural fibers can be divided into three groups namely seed hair, bast fibers, and leaf fibers depending upon the source. Some examples are cotton (seed hair), ramie, jute, kenaf (bast fibers) and sisal, abaca (leaf fibers). Table 2.1 shows some properties of natural and synthetic fibers [15]. In this project, kenaf was chosen as one of the reinforcement in the hybrid composites due to its tensile properties.

Table 2.1: Selected properties of natural and synthetic fibers [15].

Fiber	Density (g/cm^3)	Tensile Strength (MPa)	Tensile Modulus (GPa)
Kenaf	1.45	930	53
Cotton	1.51	400	13
Sisal	1.50	510	22
E-glass	2.50	3500	70
Carbon	1.40	4000	240

2.2 HYBRID COMPOSITES

Hybrid composites by definition are the process of incorporation of two or more reinforcements in a polymer resin matrix. It differs with the composite material whereby it has only one fiber reinforcement in the polymer resin matrix. Hybrid composites provide combination of properties such as tensile modulus, compressive strength, and impact strength which cannot be achieved by composite materials. Hybrid composites have been established as high efficient, high performance structural materials and their usage is increasing rapidly [16]. By mixing two or more types of fiber in a polymer resin matrix, it is possible to form a material possessing the combined advantages of individual fibers and simultaneously mitigating their less desirable properties.

According to Gururaja *et al.* [16], hybrid composites can be made in two different ways either commingling the fibers or by laminating alternate layers of the fibers. In hybridization, the properties to be obtained largely depends on the length of individual fibers, fiber loading and orientation, level of mixing, fiber to matrix bonding and the arrangement of individual fibers in the composite. In essence, the properties to be obtained in hybridizing two reinforcements can be predicted by using the rule of mixture as follow [17]

$$P_H = P_1 V_1 + P_2 V_2 \qquad \text{Equation 2.1}$$

where P_H is the property to be investigated, P_1 is the corresponding property of the first system and P_2 is the corresponding property of the second system. V_1 and V_2 are the relative hybrid volume fractions of the first and second system. However [17],

$$V_1 + V_2 = 1 \qquad \text{Equation 2.2}$$

A positive or negative hybrid effect means positive or negative deviation of certain mechanical properties from this rule. Hybrid effect has been used to describe the interesting improvement in the properties of composite imbedding two or more fibers [18]. The uses of hybrid composites have been widely used in various industries such as aeronautical, smart memory composites, wind power generation, and civil construction. In aeronautical application, aircraft must have strong properties and lightweight. This can be achieved by using materials with good properties like glass and carbon reinforced hybrid composites [19]. In wind power generation, hybrid composites have been utilized in fabrication of turbine blades of the wind turbine system. Figure 2.1 shows an example of wind turbine system made of glass and carbon reinforced hybrid composites [20].

Figure 2.1: Hybrid Wind Turbine System.

Hybrid composites have also been the main subject interest in civil construction industry over the last decade. The first hybrid fiber reinforced plastic bridge was constructed in Okinawa, Japan in 2001 [21]. This bridge is a two span continuous girder pedestrian bridge as shown in Figure 2.2.

Figure 2.2: Pedestrian Bridge in Okinawa, Japan.

2.3 KENAF FIBER

One of the most widely used natural fibers is kenaf which has been successfully incorporated in automotive application such as interior and exterior parts of car. Kenaf or its scientific name Hibiscus cannabius L. family Malvaceae is an herbaceous annual plant that can be grown under an enormous range of weather condition. It can grow more than 3 meter within 3 months even in moderate ambient conditions. Figure 2.3 shows a sample of kenaf mat. The fiber is basically extracted from the kenaf plant stalk.

Figure 2.3: Kenaf mat.

In the past, kenaf has been used as a cordage crop to produce twine, rope, canvas and sackcloth. Recently, kenaf is used as an alternative to wood in pulp and paper industries [22]. Kenaf is also used in automotive industry especially in the fabrication of interior parts of car [23], as well as fiber board [24]. Table 2.2 shows some properties of kenaf fiber [25].

Table 2.2: Properties of kenaf fiber [25].

Tensile Strength	930 MPa
Tensile Modulus	0.53 GPa
Elongation at Break	1.6%
Density	1450 kg/m^3
Fiber Diameter, D	14-33 m
Water Absorption Percentage	17 %

2.4 PET FIBER

PET is a thermoplastic polymer resin of the polyester family. It may exist in both amorphous (transparent) and semi-crystalline polymer depending on its processing and thermal history. PET is commonly referred to “polyester” while the acronym “PET” is generally used in relation to packaging. Figure 2.4 shows a sample of PET fiber.

Figure 2.4: PET fiber.

Polyester contributes to about 18% of world polymer production and it is the third-most-produced polymer after polyethylene (PE) and polypropylene (PP). PET consists of polymerized units of the monomer ethylene terephthalate with repeating $C_{10}H_8O_4$ units. PET is commonly recycled and has the number "1" as its recycling symbol. Due to its excellent barrier property, PET is widely used to produce plastic bottles for soft drinks [26]. Properties of PET were presented in Table 2.3 [27]. PET fiber has higher tensile strength and modulus compared to kenaf fiber. The presence of both fibers has completed each other and subsequently eliminates individual defects.

Table 2.3: Properties of PET Fiber [27].

Tensile Strength	2200 MPa
Tensile Modulus	10 GPa
Elongation at Break	22 %
Melting Temperature	250-265
Density	1380 kg/m^3

2.5 PROCESSING METHOD

Compression molding is one of the common processes used to produce plastics and composite materials. In compression molding, a pre shaped charge of material, premeasured volume of powder, or viscous mixture of liquid-resin and filler material is placed directly into a heated mold cavity that typically is around 200 but can be much higher. Forming process is done under pressure from a plug or from the upper half of the die. The pressure applied to the mold cavity ranges from about 10 to 150 MPa. According to Kalpakjian *et al.* [28], compression molding was mainly used with thermosetting plastics, with the original material being in a partially polymerized state.

However, according to Agarwal *et al.* [29], short-fibers reinforced thermoplastic composites are better to be produced using injection molding. Conventional mold and plunger or reciprocating screw-type machines are used for this purpose. The raw material used for injection molding of reinforced thermoplastic composites is a molding compound of the matrix and fibers in a pelletized form. Melt-blending of matrix and fibers is often carried out prior to injection molding.

Melt-blending process is aims at achieving the greater adhesion between fibers and matrix, uniform dispersion of fibers throughout the matrix and low fiber breakage so that a high aspect ratio is maintained for effective stress transfer. Melt-blending or mixing will give sufficient time and high chances for the compatibilizer to flow and attach between matrix and fibers. Therefore, better interfacial bonding between fibers and matrix can be achieved.

CHAPTER 3

METHODOLOGY

3.1 PROJECT FLOW CHART

Figure 3.1 shows the flow chart diagram of this project.

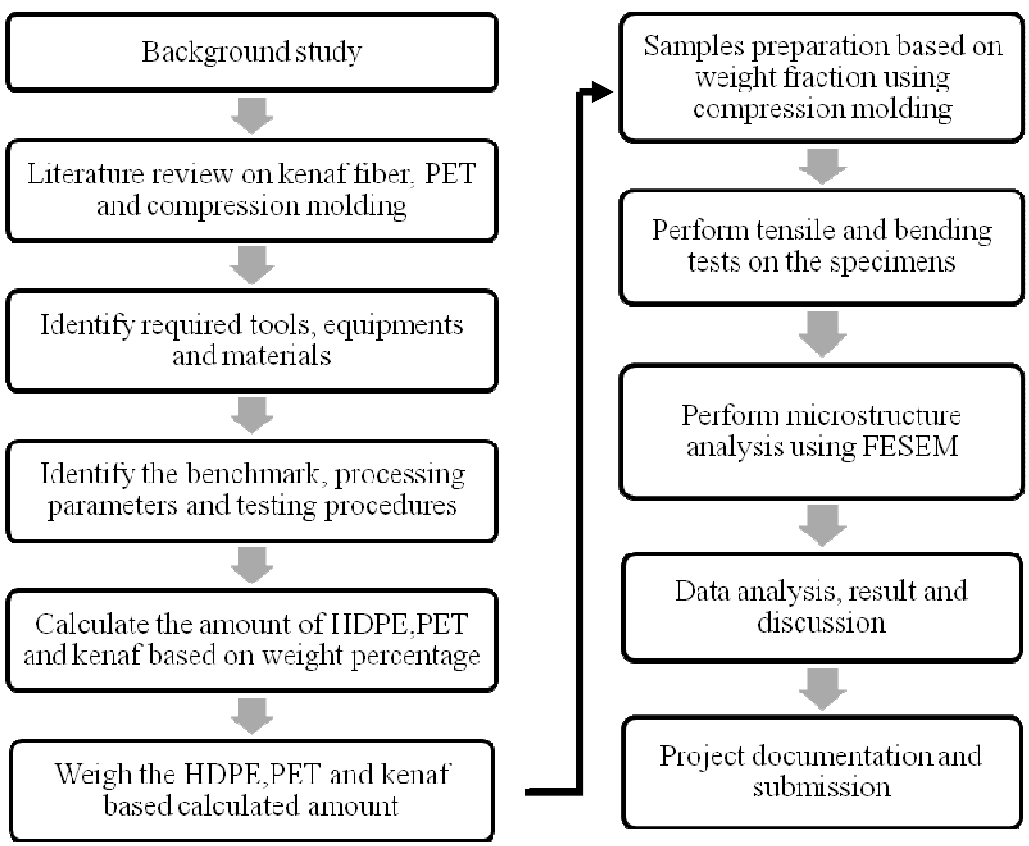


Figure 3.1: Project flow chart.

3.2 TOOLS AND EQUIPMENT

These are tools and equipment required to carry out the experiments. All the equipment are available in Block 17, UTP. Table 3.1 shows the summary of equipment and their functions.

Table 3.1: List of equipment and functions.

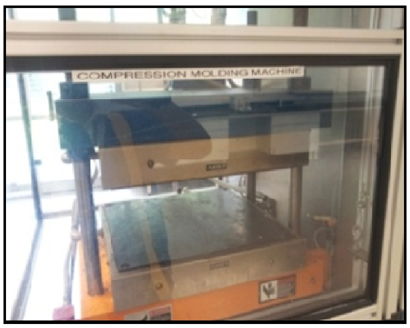
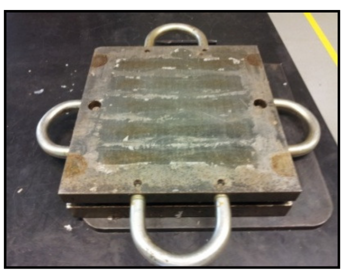
Equipment	Function
CARVER Inc Compression Molding Machine 	To compress the polymer hybrid composites into dog-bone shape for tensile and rectangle shape for flexural.
AMATEK Inc Universal Testing Machine 	To carry out the tensile test and 3-points bending test on the specimens and obtain significant mechanical properties of the composites such as tensile strength, Young's modulus, flexural strength and flexural modulus.

Table 3.1: List of equipment and functions (continued).

CARBOLITE 450 Oven 	To dry the wet kenaf fiber mat.
METTLER TOLEDO Electronic Balance 	To weigh the HDPE pellets, PET and kenaf.
Compression Mold 	Medium to compress the composite into desired shape and thickness.
Field Emission Scanning Electronic Micrograph 	To analyze the microstructure of the polymer hybrid composites and observe the bonding between fibers and matrix.

3.3 MATERIAL

3.3.1 Matrix (HDPE Titanvene HD5218EA)

High density polyethylene (HDPE) pellets were obtained from PT. TITAN Petrokimia Nusantara (Banten, Indonesia). The materials have a melt flow index of 18g/10 min at 190°C, a density of 950 kg/m^3, and melting temperature of 130°C. It can be easily processed using compression molding at the temperature in the range of 180°C to 240°C. Table 3.2 shows the properties of the HDPE obtained from its supplier [30].

Table 3.2: Properties of HDPE HD5218EA [30].

Properties	Value	Unit
Tensile Strength	23	MPa
Tensile Modulus	1.3	GPa
Elongation at Break	250	%
Charpy Impact Strength	5	kJ/m^2

3.3.2 PET Fiber

PET fiber yarn was obtained from Recron (Malaysia) Sdn. Bhd. PET fiber has a density of 1.38 kg/cm^3 and melting temperature range of 250 to 265°C. Figures 3.2 and 3.3 show the PET fiber yarn and chopped PET fiber respectively.

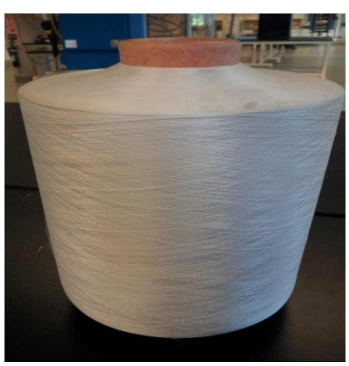


Figure 3.2: PET fiber yarn.

Figure 3.3: Chopped PET fiber.

3.3.3 Kenaf Fiber Mat

Kenaf fiber mat were obtained from Innovative Pultrusion Sdn. Bhd. (India). Surface treatment was carried out on the kenaf mat before it was processed in the samples preparation. The fibers were soaked in the 6% concentration of sodium hydroxide solution for 24 hours. Then, the fibers were washed with distilled water for 7 times to remove all the sodium hydroxide solution on its surface before it being dried in an oven at the temperature of 50^{o}C for 8 hours. Finally, the fibers were stored in a container to reduce its moisture absorption.

3.3.4 Compatibilizer

An anhydride modified polypropylene, Fusabond P 613 was obtained from DuPont Packaging & Industrial Polymers Malaysia was used in the experiment. It has a density of 0.903 g/cm^3, melting point of 162°C with a maximum processing temperature of 300°C, and melting flow index of 42 g/10 min.

3.4 SAMPLES PREPARATION

There were three types of specimens to be produced namely neat HDPE, HDPE/PET/kenaf and HDPE/PET/kenaf with 5% of Fusabond P613 compatibilizer. Neat HDPE was produced as a benchmark for result comparison. Table 3.3 shows the fibers and matrix weight fraction for each type of specimen. The composites were fabricated using laminate method. The first step of preparing the composite was producing the neat HDPE layers. The layers were produced according to the several steps discussed on the next page.

Table 3.3: Fibers and matrix weight fraction for each specimen.

Specimen	Matrix (wt.%)	PET Fiber (wt.%)	Kenaf Fiber Mat (wt.%)	Compatibilizer (wt.%)	Number of Samples	Samples Code
Neat HDPE	100	0	0	-	5	Neat HDPE
HDPE/PET/kenaf	80	10	10	-	5	80/10/10
	70	15	15	-	5	70/15/15
HDPE/PET/kenaf with compatibilizer	80	10	10	5	5	80/10/10/C
	70	15	15	5	5	70/15/15/C

Procedures of preparing neat HDPE layers were:

1. A thin layer of wax was applied on the surface of the mold for easiness composites removing.
2. 8 g of HDPE pellet was weighed using Mettler Toledo Electronic Balance and then was put inside the mold cavity.
3. The top cover of the mold was closed and the mold then was inserted into te machine.
4. CARVER Inc Compression Molding Machine was setup at $150^{o}C$ and 12 ton force pressure.
5. The mold was left preheat for about 10 minutes before it was compressed under pressure for 20 minutes.
6. Then, the mold was cooled down under pressure by using air supply and outside fan until its temperature reached $80^{o}C$.
7. The compression was stopped and the platens heat were let to be fully opened.
8. The mold was removed from the machine.
9. HDPE layers were then removed from the mold and weighed using the electronic balance.

Composition of PET and kenaf were prepared prior producing the laminate composites. Before PET and kenaf fibers were put into the mold, they were weighed accordingly based on the weight obtained from the calculation. The weight of fibers for each samples were taken and recorded. Figure 3.4 shows the example of fibers preparation prior producing the laminate composites.

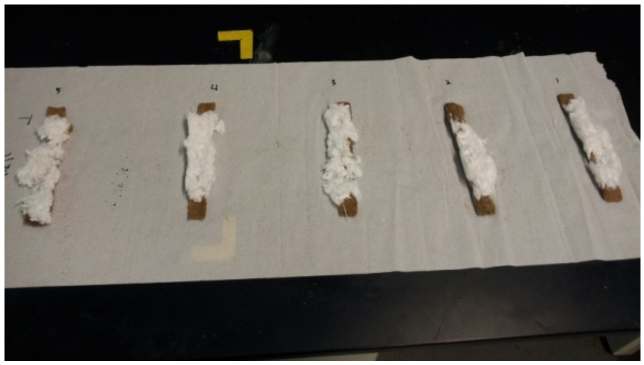


Figure 3.4: Fibers preparation.

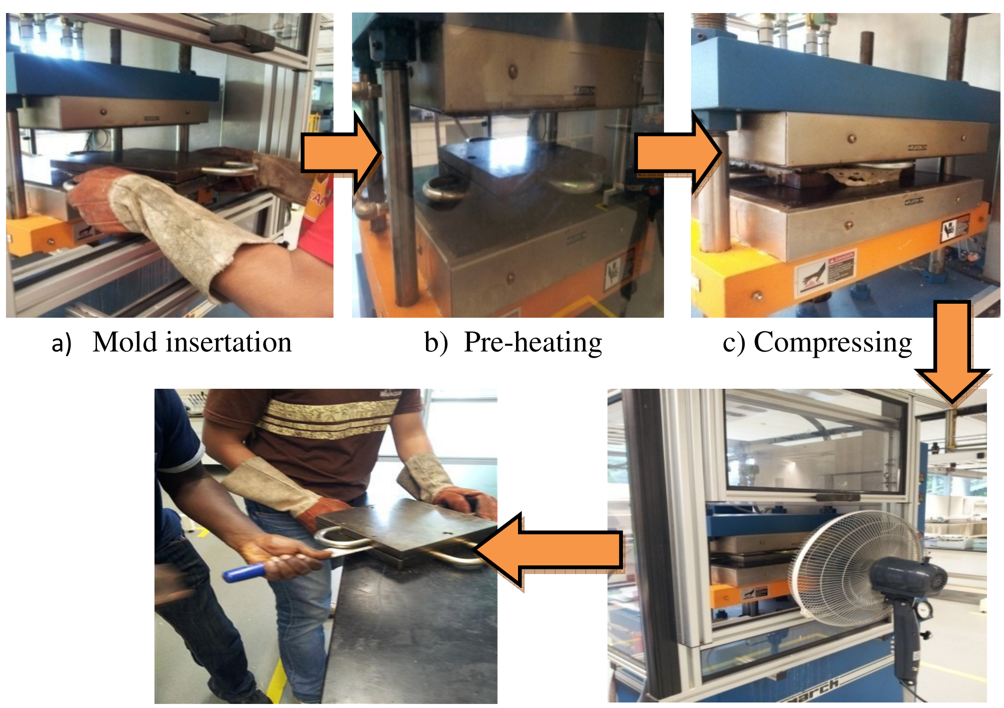
After all the fibers were done prepared, the composites were ready to be produced. The process took about 2 hours to be completed. Basically, there were five stages involved in the process which were mold loading into the machine, pre-heating, compressing, cooling under pressure and mold removing from the machine. The procedures of producing the composites were as follows:

Procedures of preparing HDPE/PET/kenaf hybrid composites were:

1. A thin layer of wax was applied on the surface of the mold for easiness composites removing.
2. A neat HDPE layer was put inside the mold cavity.
3. 10 wt.% of chopped PET fiber and 10 wt.% of kenaf fiber were put inside the mold cavity by layering them on the HDPE layer.
4. Another HDPE layer was put on top to cover the fibers so that the fibers will be in the middle between two layers of HDPE.
5. The top cover of mold was closed and the mold was inserted into the machine.
6. CARVER Inc Compression Molding Machine was setup at 210^{o}C and 12 ton force pressure.

7. The mold was left preheat for about 10 minutes before it was compressed under pressure for 20 minutes.
8. Then, the mold was cooled down under pressure by using air supply and outside fan until its temperature reached 80^{o}C.
9. The compression was stopped and the platens heats were let to be fully opened.
10. The mold was carefully removed from the machine.
11. Finally, the composites were removed from the mold and weighed using the electronic balance.
12. Steps 1-11 were repeated for different composition of fibers in the composites.

Figure 3.5 shows the summary of main stages involved in producing the hybrid composites using compression molding. Figure 3.6 shows all the specimens that have successfully been produced consist of tensile dog-bone shape and rectangular shape for flexural testing.



a) Mold insertation b) Pre-heating c) Compressing

d) Composite removing e) Cooling

Figure 3.5: Summary of samples preparation using compression molding technique.

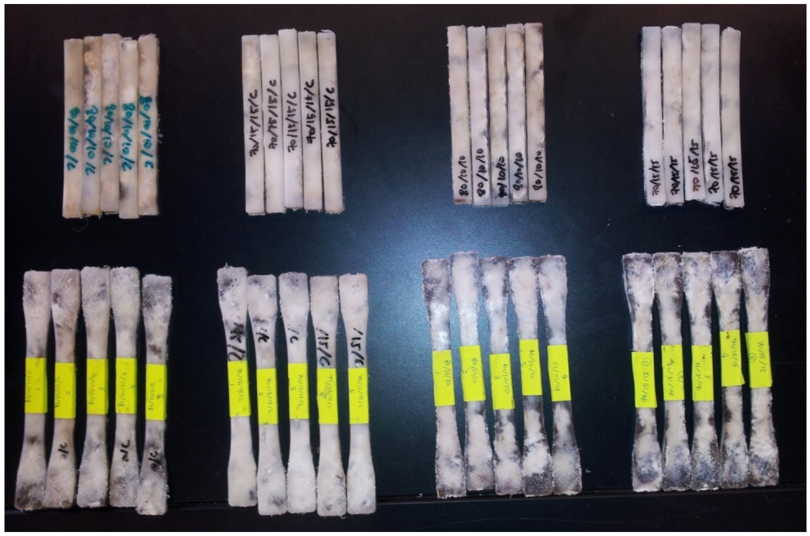


Figure 3.6: HDPE/PET fiber/kenaf fiber mat composites.

3.5 TENSILE TEST

Tensile test was conducted on five specimens at room temperature of 25 using the Universal Testing Machine (model LLOYD). The specimens were tested based on ASTM standard D638 Type 1 as shown in Figure 3.7. The specimen dimensions were presented in the Table 3.4 [31].

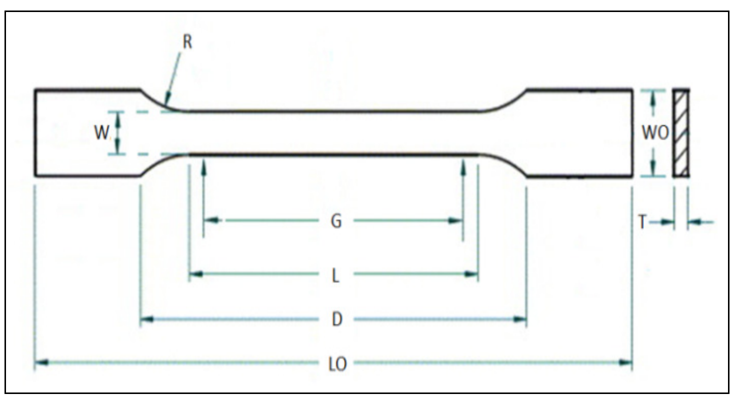


Figure 3.7: Type 1 dimension of dog-bone shape specimen.

Table 3.4: Specimen dimensions for tensile specimen [31].

Dimensions	Length (mm)
W – Width of narrow section	13 ± 0.5
L – Length of narrow section	57 ± 0.5
WO – Width overall	19 ± 6.4
LO – Length overall	165
G – Gage length	50 ± 0.25
D – Distance between grips	115 ± 5
R – Radius of fillet	76 ± 1
T – Thickness	7 or under

Procedures of conducting tensile test were as follows:

1. Firstly, software “Nexygen” and “LRX Console” were run.
2. An appropriate height of the crosshead was adjusted so that the specimen could be placed.
3. Specimen was placed inside the grips.
4. Then, laser sensor was switched on followed by an adjustment of the tape so that the gap between the two tapes is exactly “10.00” as displayed by the sensor.
5. The position of the grips was set to zero.
6. “Play” button was clicked to start the test.
7. The machine will automatically stop when the specimen fails.
8. All the data such as tensile strength and modulus were taken and recorded.

3.6 FLEXURAL TEST

Bending test was conducted on five specimens at room temperature of 25

using Universal Testing Machine (model LLOYD). The specimens were tested based on ASTM standards D790 [32]. The recommended dimension for the thermoplastic molded material of the specimen was 127 x 12.7 x 3.2 mm as shown in the Figure 3.8. The setup of 3-point bending test was shown in Figure 3.9.

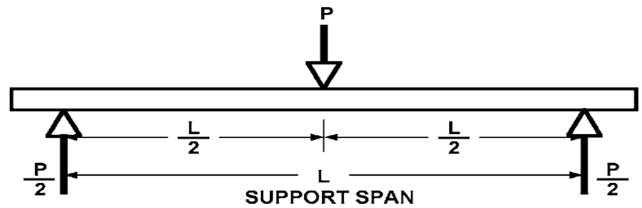


Figure 3.8: Loading diagram of 3-points bending test [32].

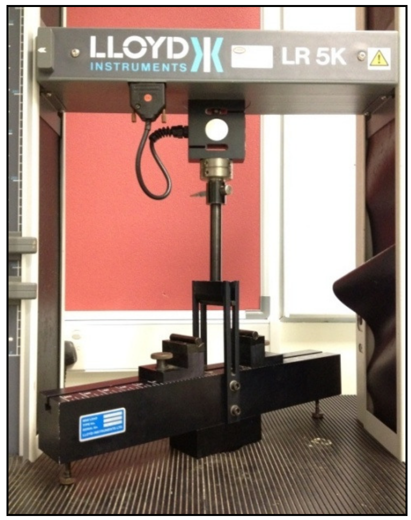


Figure 3.9: Set-up for 3-point bending test.

The procedures of conducting the test were as follows:

1. Flexural accessories were attached to the Universal Testing Machine.
2. Then, software “Nexygen” and “LRX Console” were run.
3. After that, the machine was switched on.
4. Specimen was placed right on the middle of the supports.
5. The position of the grips was set to zero.
6. “Play” button was clicked to start the test.
7. The machine will automatically stop when the specimen fails.

3.7 GANTT CHART AND KEY MILESTONES

Gantt chart on the next page shows the relationship between work and time. It contains key milestones and time allocated to complete each work. Figure 3.8 shows the key milestones in final year project.

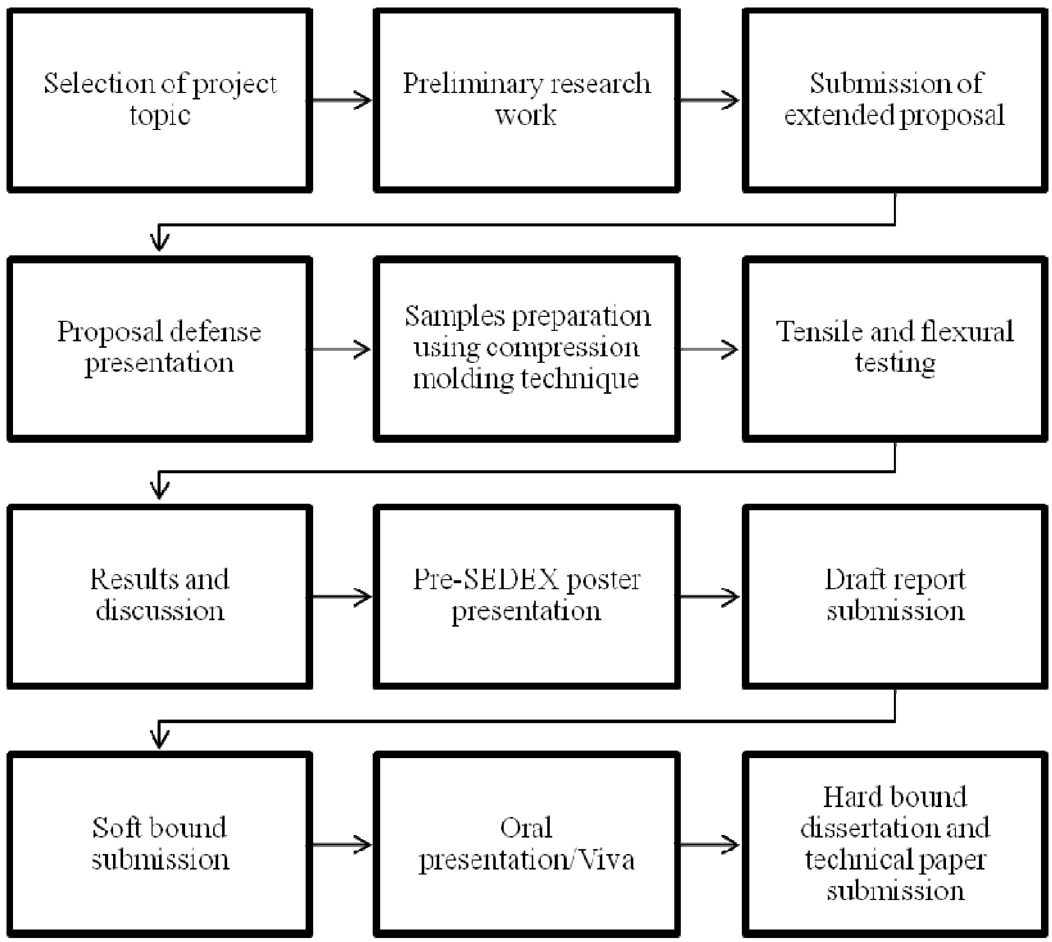
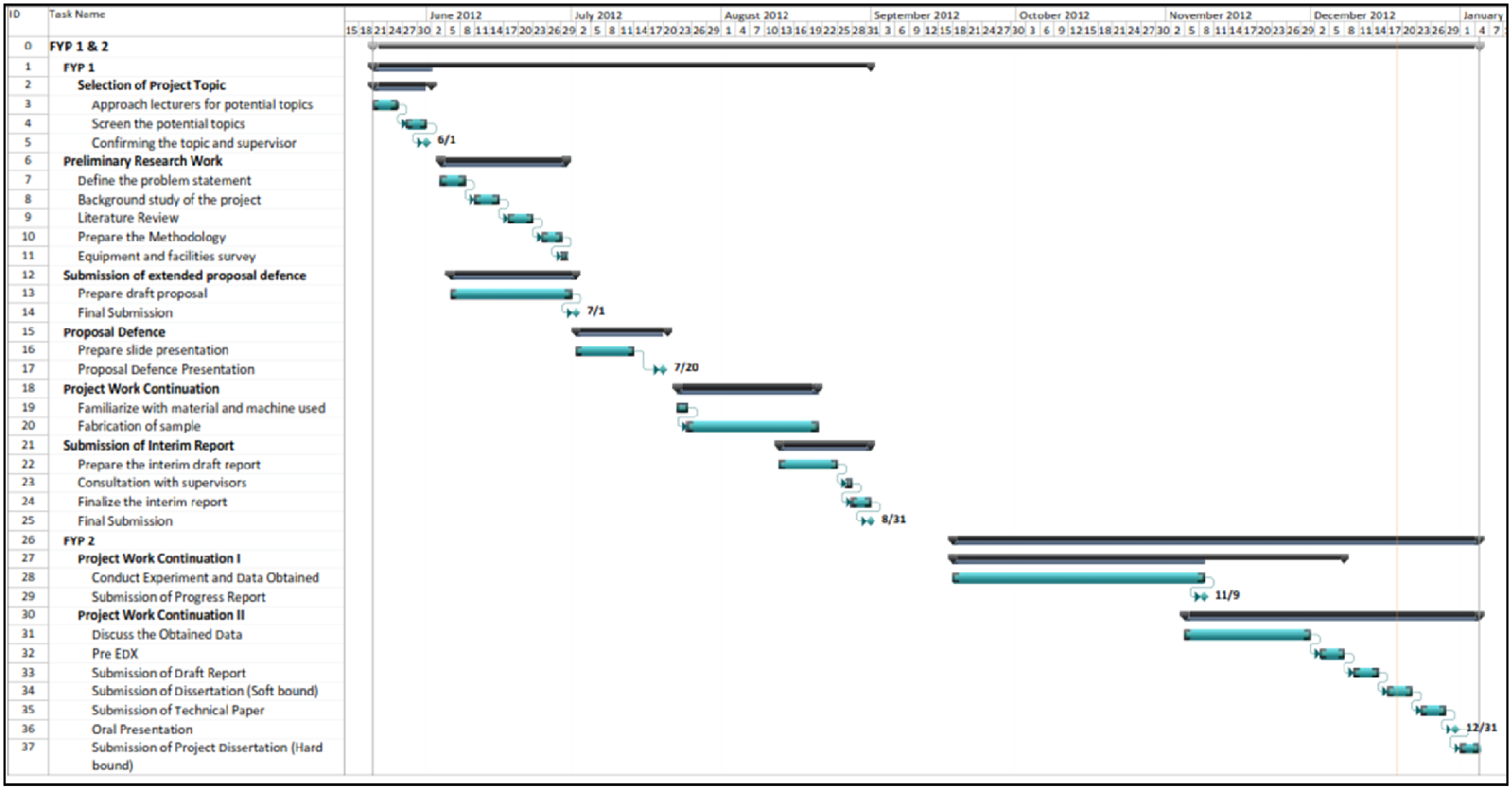


Figure 3.10: Key Milestones.

Table 3.5: Summary of project activities and key milestones for FYP 1 and FYP 2.



CHAPTER 4

RESULTS & DISCUSSION

In this chapter, a theoretical tensile strength and modulus for neat HDPE, HDPE/PET/kenaf 80/10/10 vol.% and 70/15/15 vol.% are calculated using rule of mixture formula. Experimental results from tensile and flexural tests were tabulated and discussed further. The results value used are the average value from five specimens tested. Theoretical results were compared to the experimental results at the end of this chapter.

4.1 THEORETICAL RESULTS

4.1.1 Design Calculation Formula (Rule of Mixture).

Table 4.1 shows the calculation formula to find the theoretical tensile strength and tensile modulus of hybrid composites.

Table 4.1: Design calculation formula [33].

Properties	Formula
Tensile Strength	$\sigma_c = \sigma_{f1}V_{f1} + \sigma_{f2}V_{f2} + \sigma_m V_m$
Tensile Modulus	$E_c = E_{f1}V_{f1} + E_{f2}V_{f2} + E_m V_m$

Where: Tensile strength of composite | Tensile strength of fiber

Tensile strength of matrix | Elastic modulus of composite

Elastic modulus of fiber | Elastic modulus of matrix

Volume fraction of matrix | Volume fraction of fiber

4.1.2 Sample Calculation.

Assumptions:

1) Fiber 1 = 15 vol.%
2) Fiber 2 = 15 vol.%
3) Matrix = 70 vol.%

Tensile strength of composite,

$$\sigma_c = \sigma_{f1}V_{f1} + \sigma_{f2}V_{f2} + \sigma_m V_m$$

$$\sigma_c = (427)(0.15) + (22$$

Elastic Modulus of composite, E_c

$$E_c = E_{f1}V_{f1} + E_{f2}V_{f2} + E_m V_m$$

$$E_c = (53)(0.15) + (10000)$$

$$E_c = 2.42\ GPa$$

From the calculation above, the theoretical tensile strengths and tensile moduli for different samples composition were tabulated in Table 4.2.

Table 4.2: Theoretical results.

Samples	Matrix (vol.%)	PET Fiber (vol.%)	Kenaf Fiber (vol.%)	Tensile Strength (MPa)	Tensile Modulus (GPa)
Neat HDPE	100	0	0	23.00	1.30
80/10/10	80	10	10	281.10	2.05
70/15/15	70	15	15	410.15	2.42

Figure 4.1 shows the relationship between volume fraction of fiber and tensile strength. It is clearly shown that the higher the fiber volume fraction, the higher the tensile strength.

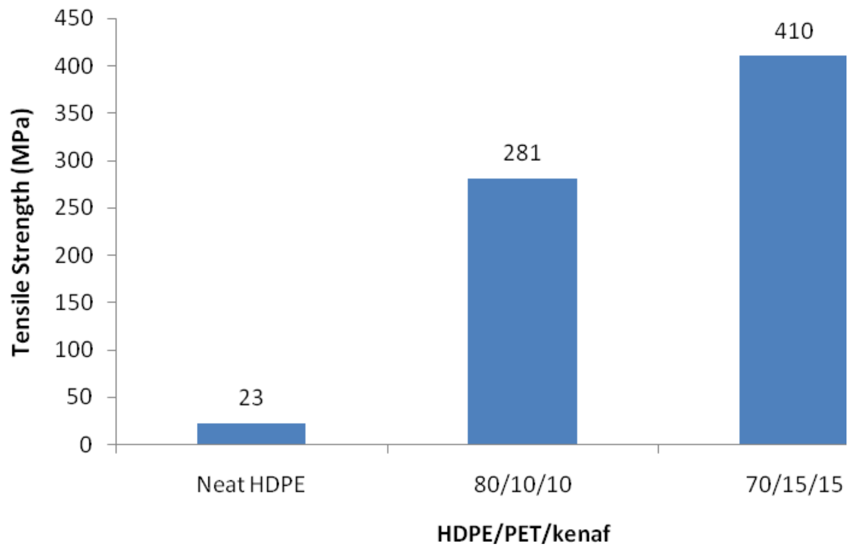


Figure 4.1: Theoretical tensile strengths of HDPE/PET/kenaf hybrid composites.

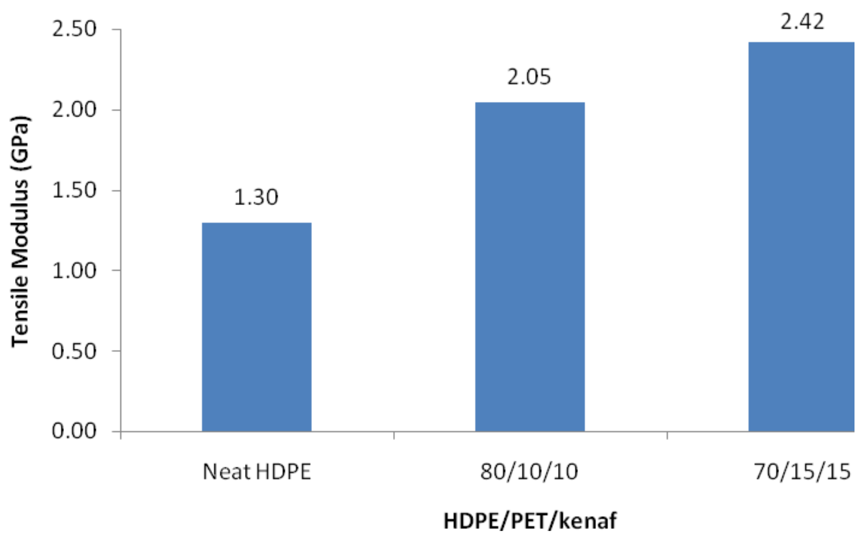


Figure 4.2: Theoretical tensile moduli of HDPE/PET/kenaf hybrid composites.

Figure 4.2 above shows the relationship between tensile modulus and volume fraction of fibers. Thus, it can be concluded that the tensile modulus is linearly proportional to the fibers volume fraction.

4.2 TENSILE PROPERTIES

The results from tensile test were tabulated in Tables A1 and A2 (Appendix) before being summarized in Figures 4.3 and 4.4. Generally, it can be said that the fibers loading significantly affect the mechanical properties of the composites. The fibers have proven their function by increasing the tensile strength of the hybrid composites compared to neat HDPE. Based on both graphs, tensile strength and tensile modulus of 80/10/10 wt.% of HDPE/PET/kenaf improved by approximately 21% and 32% respectively compared to neat HDPE. Tensile strength of 70/15/15 wt.% of HDPE/PET/kenaf showed decrement of 11% compared to neat HDPE. However, for tensile modulus, 70/15/15 wt.% showed some improvement by 3% compared to neat HDPE. Nevertheless, when compared to 80/10/10 wt.%, 70/15/15 wt.% showed decrement of 27% and 22% in tensile strength and tensile modulus respectively. One possible explanation is the inclusion of 30% fibers into the matrix has led to poor interfacial bonding between matrix and fibers due to insufficient matrix to wet the fibers completely. This suggesting that the optimal fiber content to achieve highest improvement in tensile strength and modulus was 20 wt.%.

It is also can be observed that the addition of compatibilizer had no effects on improving the tensile strength and modulus of the composites. Tensile strength of 80/10/10/C wt.% and 70/15/15/C wt.% showed decrement by approximately 23% and 11% compared to 80/10/10 wt.% and 70/15/15 wt.% respectively. For tensile modulus, 80/10/10/C wt.% and 70/15/15/C wt.% showed decrement of 17% and 11% compared to 80/10/10 wt.% and 70/15/15 wt.% respectively. Initially, compatibilizer should play a role as an adhesive between HDPE matrix and fiber reinforcements. However, in this case, compatibilizer had failed to increase the tensile properties of the composites. According to Aji *et al*. [18], compatibilizer will give an optimum hybridization effect when it is melt blended with matrix and fibers before going through compression molding process. The melt-mixing process will give sufficient time and high chances for compatibilizer to attach between fibers and matrix and thus increase their adhesion.

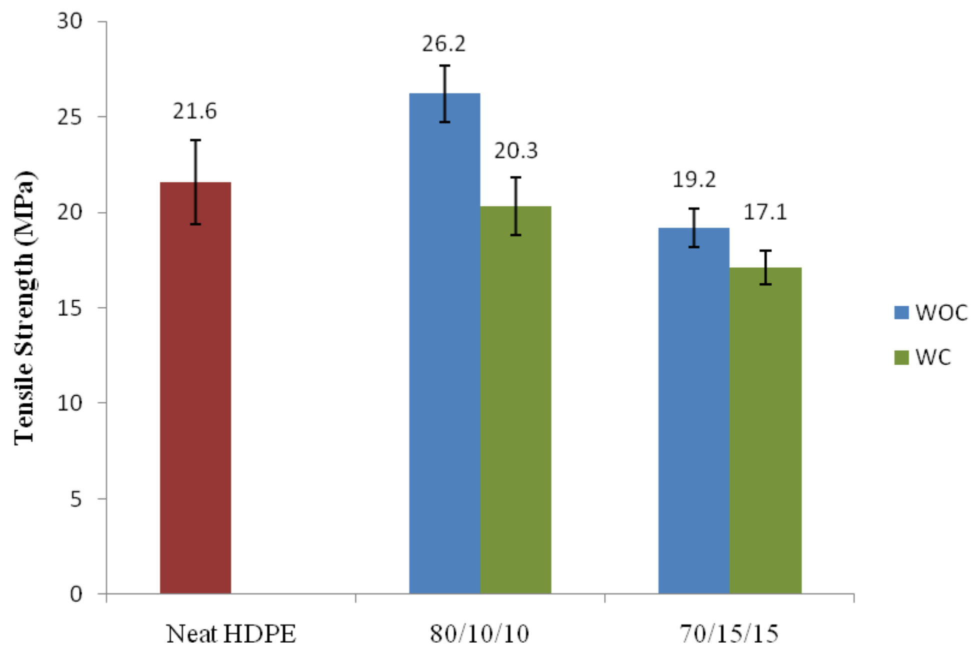


Figure 4.3: Tensile strength of HDPE/PET/kenaf hybrid composites.

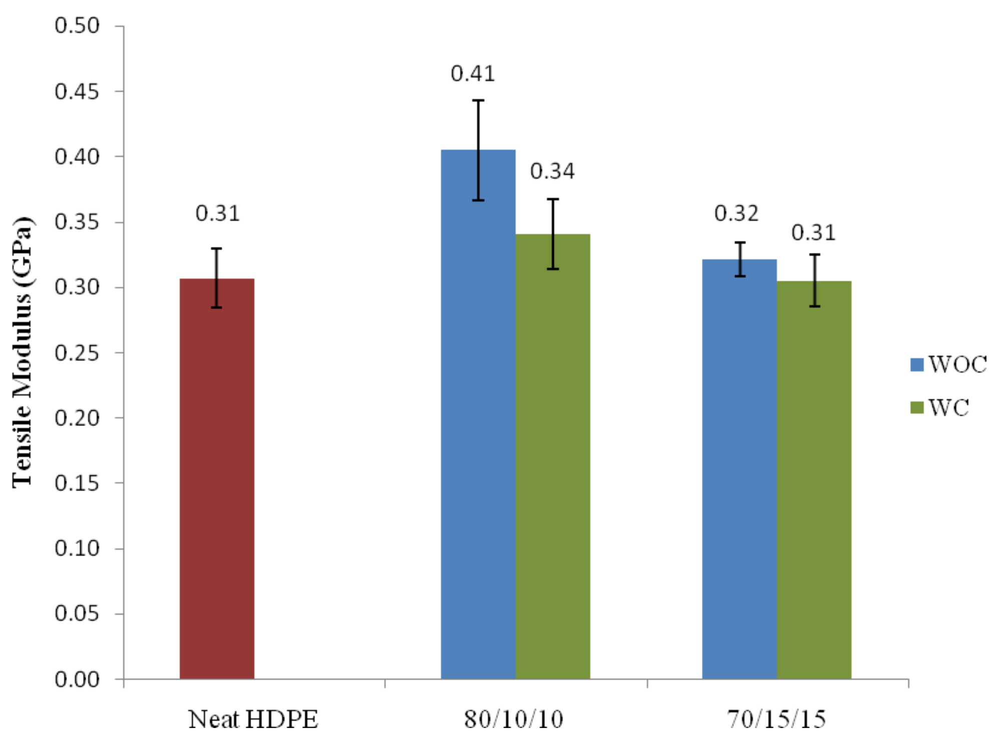


Figure 4.4: Tensile modulus of HDPE/PET/kenaf hybrid composites.

Morphological characteristics of two samples 70/15/15 wt.% and 80/10/10 wt.% were studied using Field Emission Scanning Electron Microscope (FESEM) as shown in Figures 4.5 and 4.6. There are clear evidences of poor bonding and good bonding in 70/15/15 wt.% and 80/10/10 wt.%. In Figure 4.5, it can be clearly seen that voids are present in the microstructure of 70/15/15 wt.% composite. It is also can be observed that the fibers are not completely wetted by the matrix due to fibers abundance and insufficient matrix. In Figure 4.6, it can be seen that no voids are present and the fibers are completely wetted by the matrix and therefore, increase the interfacial bonding between fibers and matrix. As a result, tensile properties of 80/10/10 wt.% are better than 70/15/15 wt.%.

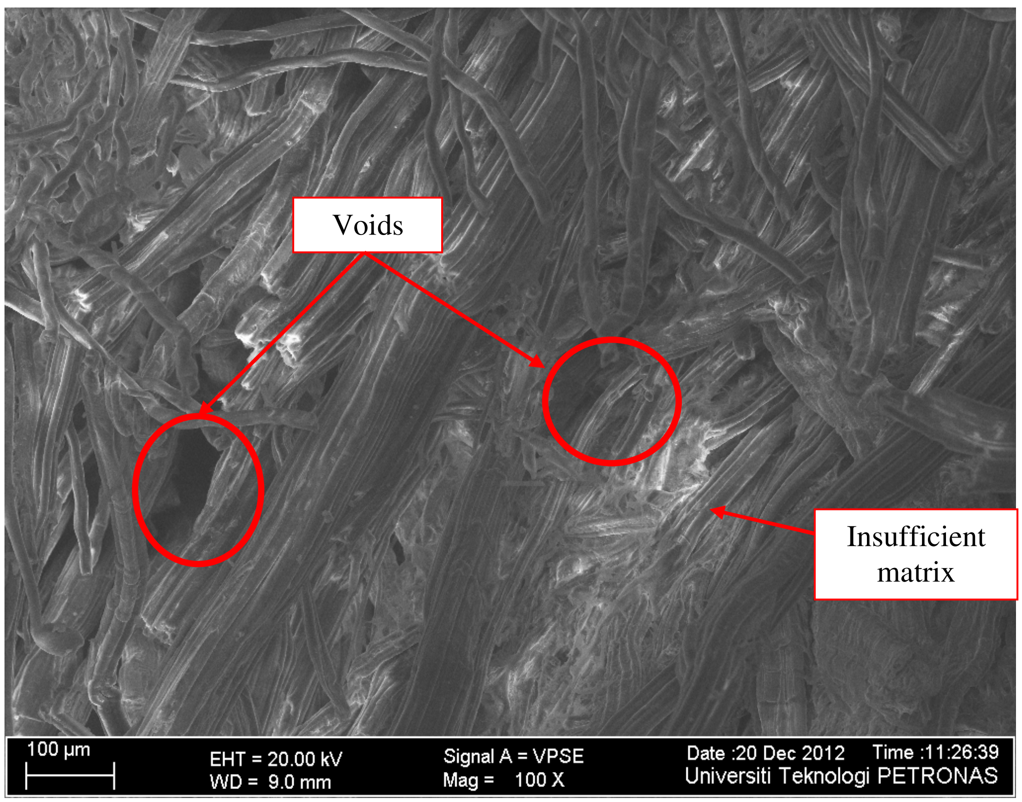


Figure 4.5: FESEM of 70/15/15 wt% HDPE/PET/kenaf hybrid composites.

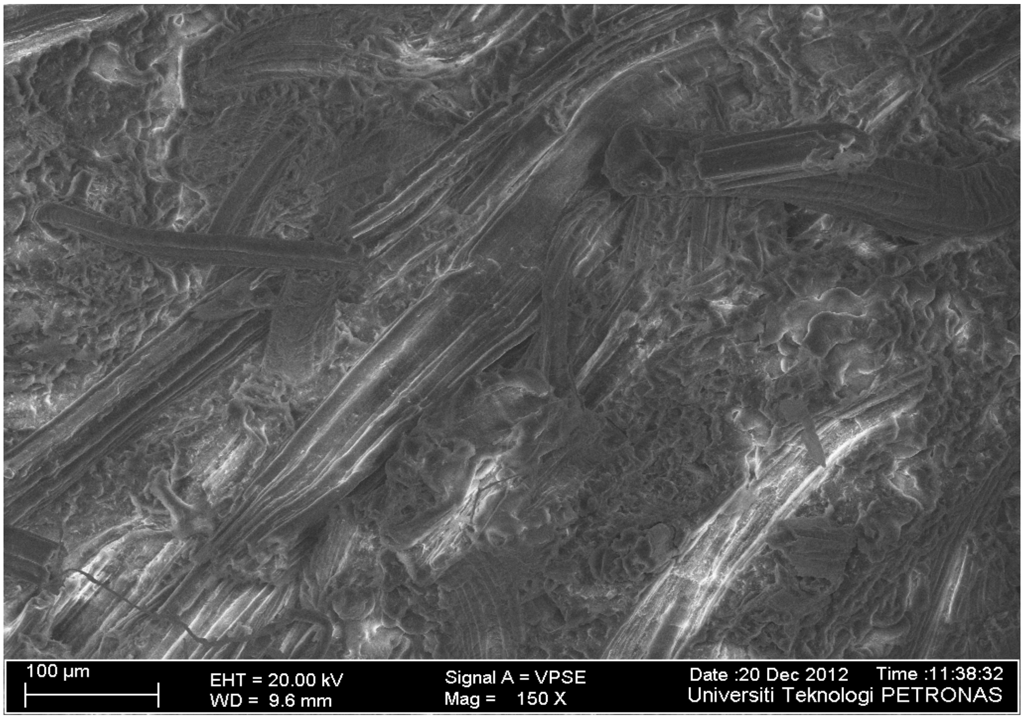


Figure 4.6: SEM of 80/10/10 wt% HDPE/PET/kenaf hybrid composites.

4.3 FLEXURAL PROPERTIES

The results from flexural test were tabulated in Tables A3 and A4 (Appendix) before being summarized in Figures 4.7 and 4.8. Based on both graphs, flexural strength and flexural modulus of 80/10/10 wt.% of HDPE/PET/kenaf improved by 33% and 34% respectively compared to neat HDPE. 70/15/15 wt.% of HDPE/PET/kenaf showed highest improvement of flexural strength and flexural modulus with 40% and 51% improvement respectively compared to neat HDPE. Nevertheless, when compared to 80/10/10 wt.%, 70/15/15 wt.% showed increment of 6% in both flexural strength and flexural modulus. One possible explanation is the inclusion of 30% fibers into matrix has led to better matrix dispersion throughout the specimens. When force applied perpendicularly to the specimens, the load is transferred equally to the fibers resulted in better resistance to bending deformation under load. This suggesting that the optimal fiber content to achieve highest improvement in flexural strength and modulus was 30 wt.%.

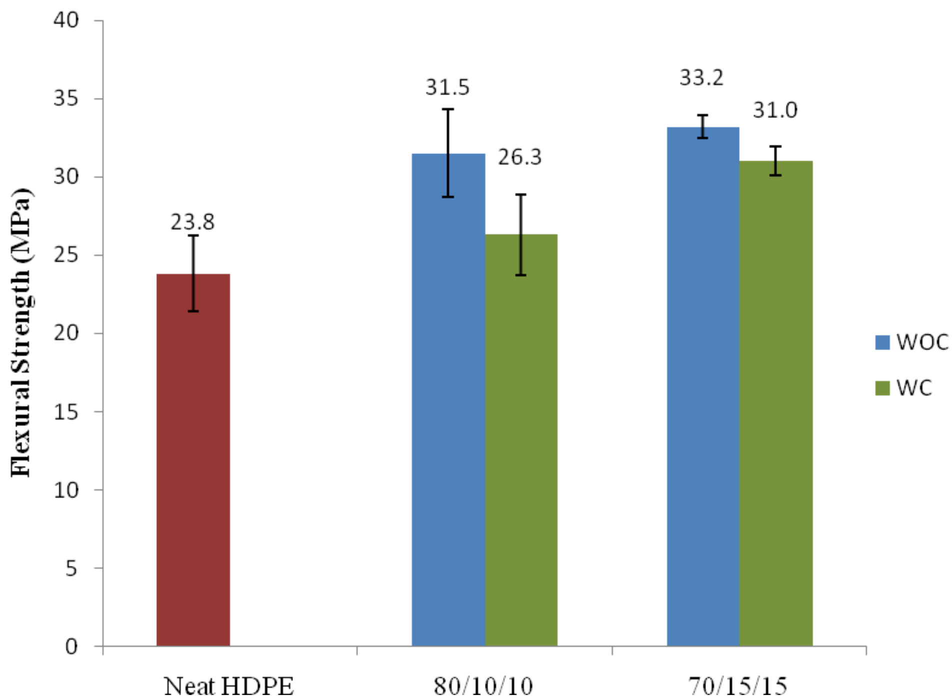


Figure 4.7: Flexural strength of HDPE/PET/kenaf hybrid composites.

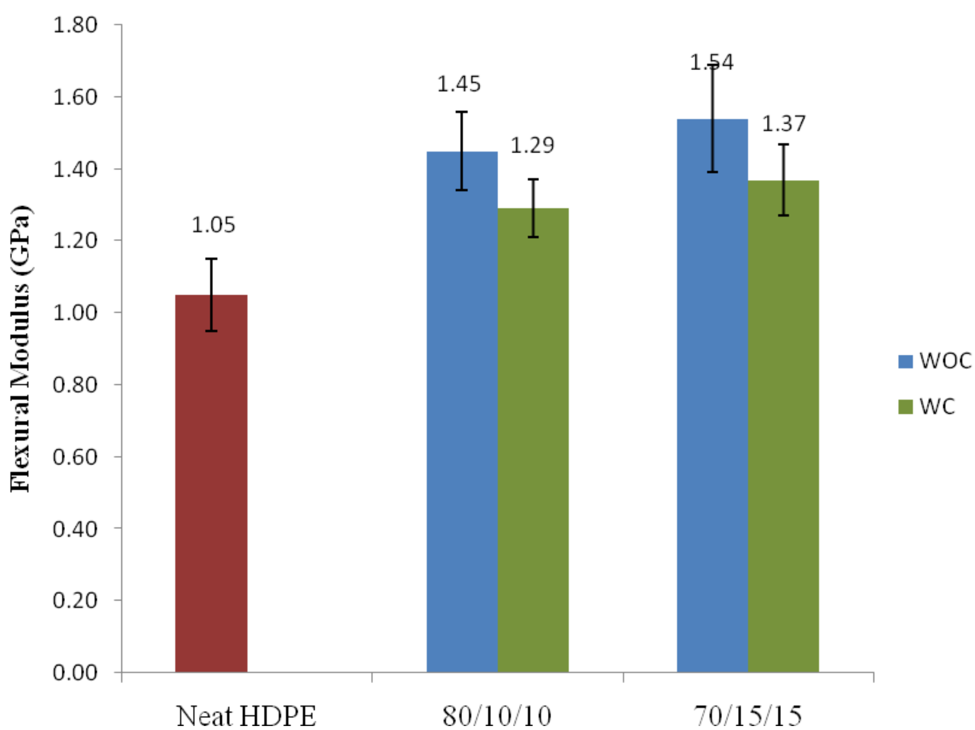


Figure 4.8: Flexural modulus of HDPE/PET/kenaf hybrid composites.

The addition of compatibilizer had no significant improvement with 17% and 7% decrement in flexural strength compared to HDPE/PET/kenaf 80/10/10 wt.% and 70/15/15 wt.% respectively. For flexural modulus, 80/10/10/C wt.% and 70/15/15/C wt.% showed decrement of 11% compared to 80/10/10 wt.% and 70/15/15 wt.% respectively. Initially, compatibilizer should play a role as an adhesive between HDPE matrix and fiber reinforcements. However, in this case, compatibilizer had failed to increase the flexural properties of the composites. According to Aji *et al.* [18], compatibilizer will give an optimum hybridization effect when it is melt blended with matrix and fibers before going through compression molding process. The melt-mixing process will give sufficient time and high chances for compatibilizer to flow and attach between matrix and fibers and therefore increase the adhesion between them. There were also much difference between theoretical results and experimental results as theoretical results were calculated by assuming that there would be perfect bonding between fibers and matrix, zero experimental errors and good fibers dispersion throughout the specimens.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Tensile properties and flexural properties of HDPE/PET/kenaf hybrid composites had been investigated. HDPE/PET/kenaf of 80/10/10 wt.% showed highest improvement in tensile strength and modulus with 21% and 32% respectively compared to neat HDPE. This indicated that the optimal fibers content to achieve highest tensile strength and modulus of the hybrid composites was 20%. FESEM micrographs had proven that there were no voids and the fibers were completely wetted by the matrix in the 80/10/10 wt.% microstructure. Subsequently, 80/10/10 wt.% had higher tensile properties than 70/15/15 wt.% due to better interfacial bonding between fibers and matrix. Better fibers dispersion in HDPE/PET/kenaf of 70/15/15 wt.% had resulted in significant improvement of 40% and 51% in flexural strength and flexural modulus respectively. Therfore, the optimal fibers content to achieve highest flexural properties was 30%. The addition of compatibilizer had failed to increase the tensile and flexural properties of the hybrid composites suggesting that the result would be better if melt-blending of matrix, fibers and compatibilizer was done prior to compression molding.

5.2 Recommendation

The recommendations for this project are as follow:

1) Fabrication of HDPE/PET/kenaf hybrid composites should be made using injection molding for better adhesion between fibers and matrix.
2) Melt-blending of matrix, fibers and compatibilizer should be done prior compression molding.

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APPENDICES

Table A1: Tensile strength of HDPE/PET/kenaf hybrid composites.

Sample	Tensile Strength (MPa)				
	Neat HDPE	80/10/10 wt.%	80/10/10/C wt.%	70/15/15 wt.%	70/15/15/C wt.%
1	19.65	24.21	20.78	18.25	15.56
2	23.69	26.00	18.34	18.03	17.43
3	20.41	27.80	19.67	20.02	17.32
4	20.16	27.41	22.53	20.21	16.98
5	24.30	25.42	20.00	19.43	18.01
Avg	21.64	26.17	20.27	19.19	17.06
Std	2.18	1.47	1.54	1.00	0.92

Table A2: Tensile modulus of HDPE/PET/kenaf hybrid composites.

Sample	Tensile Modulus (GPa)				
	Neat HDPE	80/10/10 wt.%	80/10/10/C wt.%	70/15/15 wt.%	70/15/15/C wt.%
1	0.33	0.39	0.35	0.32	0.31
2	0.29	0.37	0.34	0.33	0.31
3	0.33	0.42	0.31	0.31	0.33
4	0.31	0.47	0.32	0.35	0.28
5	0.28	0.38	0.38	0.29	0.30
Avg	0.31	0.41	0.34	0.32	0.31
Std	0.02	0.04	0.02	0.03	0.02

Table A3: Flexural strength of HDPE/PET/kenaf hybrid composites.

Sample	Flexural Strength (MPa)				
	Neat HDPE	80/10/10 wt.%	80/10/10/C wt.%	70/15/15 wt.%	70/15/15/C wt.%
1	23.15	31.20	20.93	22.59	26.43
2	20.43	36.04	26.38	33.10	31.98
3	27.16	37.10	18.38	32.53	29.53
4	23.79	28.56	23.42	33.99	27.46
5	24.47	34.77	29.06	31.31	31.44
Avg	23.80	31.50	33.20	26.30	30.98
Std	2.42	2.79	0.71	2.58	0.92

Table A4: Flexural modulus of HDPE/PET/kenaf hybrid composites.

Sample	Flexural Modulus (GPa)				
	Neat HDPE	80/10/10 wt.%	80/10/10/C wt.%	70/15/15 wt.%	70/15/15/C wt.%
1	1.21	1.45	1.26	1.52	1.29
2	1.10	1.55	1.38	1.34	1.49
3	0.98	1.32	1.19	1.74	1.24
4	0.99	1.35	1.35	1.61	1.39
5	0.97	1.57	1.27	1.49	1.43
Avg	1.05	1.45	1.37	1.54	1.37
Std	0.10	0.11	0.08	0.15	0.10