Tensile and Flexural Properties of HDPE/Kenaf Composites with & without Compatibilizer

by

Muhammad Khalil b Azman

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

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CERTIFICATION OF APPROVAL

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Approved by,

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TRONOH, PERAK

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 person.

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(MUHAMMAD KHALIL B AZMAN)

ABSTRACT

This project focuses on the tensile and flexural properties of natural fibers composites and the effects of compatibilizer on mechanical properties. In this study, HDPE/kenaf composites with and without compatibilizer were produced. The composites were prepared with 20%, 30% and 40% (wt.%) of fiber content. Continuous kenaf long fibers were layered between the layers of HDPE and fabricated by the compression moulding method. A maleic anhydride compatibilizer is added together to enhance the interfacial bonding of matrix-fiber in the composites. Tensile and flexural tests were done on the samples and the improvements on interfacial bonding of matrix-fiber were proved under field emission scanning electron microscope (FESEM). The tested results were compared to the tensile and flexural properties of neat HDPE. It was observed that the effects of compatibilizer are significant on the tensile properties at 40% wt. of fiber content, with improvement of 214% and 347% on tensile strength and modulus, respectively. However, adverse effects of compatibilizer on tensile and flexural properties were observed in other fiber contents compared to that of specimens without compatibilizer.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

In the early 1990s, thermoplastic polymers were introduced as the most promising materials due to their unique attributes such as light weight, easy to process, corrosion resistance and recyclable [1]. Therefore, they are very attractive for various applications. For instance, high-density polyethylene (HDPE) polymer is used in chemical resistance piping system, bottle and food storage, and fuel tanks for vehicles.

However, there are some problems encountered due to the usage of plastics in industries. The main problem is the resources to make a polymer, which is petroleum, is depleting with time. Due to the limited sources, the cost of using polymer in industries is increasing. Besides, polymers do not have enough strength to be used by itself in certain applications such as in structural applications. Thus, reinforcement is needed to add strength and rigidity to the materials.

In 1930, an unexpectedly accident occurred during an experiment conducted by a young researcher from Corning Glass company which led to the modern era of composites. The researcher, Dale Kleist [1] had been attempting to weld two glass blocks together to form an airtight seal. Unexpectedly, a jet of compressed air hit a stream of the molten glass and created a shower of glass fibers, showing Dale an easy method to create fiberglass. This incident led to the beginning of the Fiber Reinforced Polymer industry.

Fiber reinforced composite industry have been expanding recently due to benefits they offer compared to neat plastic materials such as typically stronger than those neat polymers. Fiber reinforced composites consists of strong fibers surround with typically amorphous matrix materials that protect and orient the fibers. The strong and stiff but brittle fibers are set in a tough but more ductile matrix, resulting in a material with excellent strength-to-weight ratio, stiffness, and fatigue resistance [2]. Thus, fiber reinforced composites have become a better choice of materials for many applications.

As time goes by, awareness all over the world concerning protecting the environment has increase and attracted the scientists and researchers to look for environmental friendly material. Numerous attempts are done to find the alternative ways to fulfill the needs and demands of the industry, among them is producing improved materials in terms of performance of strength, weight, energy conservation, properties, and also cost.

Natural fiber reinforced plastic composite appears as the most preferable solution because of the advantages presented such as availability, renewability, low density, high specific strength, low cost and environmental friendly. Natural fibers are found to have a higher specific strength compared to glass fiber. They exhibits the properties of low density (1.2 - 1.6 g/cm^3) as compared to glass fiber (2.4 g/cm^3), thus ensures the production of lighter composites [3]. With these properties and cheaper resources, this natural fiber reinforced polymer composite theoretically offers desirable specific strength and modulus at a lower cost.

1.2 Problem Statement

Limited studies have been done on the mechanical properties of continuous fiber reinforced HDPE. Only few researchers focus on the effects of using compatibilizer on HDPE/kenaf composites. The potential benefits of this project are enhanced mechanical properties and environmental friendly materials.

1.3 Objective of the study

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

1.4 Scope of the Study

The project focused on investigating the mechanical properties of kenaf fiber reinforced HDPE composite which were tensile and flexural properties and the effects of using compatibilizer towards the mechanical properties. In this study, a continuous kenaf long fiber was fabricated with the matrix in form of pellets. Compression moulding method was used to produce the test specimen. A maleic anhydride polypropylene compatibilizer was used together to produce the composites with the compatibilizer. Characterization of the sample was done by using Field Emission Scanning Electron Microscope (FESEM).

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of natural fiber composites

The interest on the usage of natural fibers as reinforcement in fiber reinforced plastics to replace synthetic fibers such as glass is growing recently due to the benefits of natural fibers such as renewability, low density, and high specific strength. Many studies have been conducted to investigate the development of biodegradable composite materials using natural fibers such as flax and kenaf as a reinforcement for the polymers [5, 6]. Therefore, it is necessary for us to have a clear understanding on the properties and characteristic of natural fibers before we use it as an alternative material to synthetic fibers.

The main properties exhibit by natural fibers is their positive environmental impact, which is a renewable and biodegradable source. Due to its renewability, they are available at a cheaper price compared to synthetic fibers. Besides, they offer a safe working condition where their processing is environmental friendly, hence can contribute to a reduction in risk of dermal or respiratory problems. Natural fibers are also non-abrasive towards mixing and moulding equipment, hence it can reduce the equipment maintenance cost [6].

A study on natural fibers by Alvarez *et al.* [6] states that natural fibers generally contain large amounts of the hydroxyl group, which make them polar and hydrophilic in nature, while most of the plastics are hydrophobic in nature. This polar property will result in high moisture absorption in natural fibers based composites, leading to fiber swelling and voids in the matrix interphase due to lack of good

adhesion between the fiber with the polymeric matrices. Thus, this absorption will lead to alterations in weight and dimensions, as well as in strength and stiffness of the materials itself. Therefore, the fiber surface has to be modified in order to increase adhesion between them. As mention by Zampaloni *et al* [8], the alkaline solution regenerated the lost cellulose and dissolved unwanted microscopic pits or cracks on the fiber resulting in better fiber matrix adhesion. To get better mechanical properties of the composites, coupling agent can be used because it have two functions; to react with –OH groups of the cellulose and to react with the functional groups of the matrix with the goal of facilitating stress transfer between the fibers and the matrix, thus improve the interfacial bonding.

In this project, a kenaf fiber reinforced HDPE composite will be fabricated and tested to investigate the mechanical properties of the composite. Therefore, it is important for us to study the properties and characteristic of kenaf fibers before using it with the HDPE matrix to obtain their mechanical properties.

2.2 Overview of kenaf fibers and High Density Polyethylene (HDPE)

2.2.1 Kenaf fibers

Kenaf or its scientific name Hibiscus Cannabinus (Malvaceae family plant) is shown in Figure 2.1. Kenaf is popular as an important source of fiber for composites and other industrial applications [9].

Figure 2.1: Kenaf plant [9].

Kenaf has advantages on economic and ecological perspective compared to other natural fibers. Kenaf plant is able to grow under a wide range of weather conditions, such as in a cool region (average temperature 22°C and a warm region (average temperature 30°C) [10]. It can achieve an average height of more than 3 m with a base diameter of 3–5 cm, just in 3 month after sowing the seeds [11]. Kenaf fiber was priced about US $ 565 / Ton, which is cheaper if compared to glass fiber which is up to US $ 1,700 - 2,800 / Ton [12, 13].

Furthermore, 15 MJ of energy is required to produce 1 kg of kenaf fiber, compared to 54 MJ energy required to produce 1 kg of glass fiber [14]. Thus, kenaf fiber is inexpensive and high renewability resource which requires low energy consumption when being compared to a synthetic fiber. Kenaf fiber is traditionally used as ropes, canvas, and sacking. Recently, the usage of wood used in pulp and paper industries has been replaced by new alternative raw material, which is kenaf fiber to prevent the destruction of forests. Besides, it has also been used in the automotive and textiles application as a non-woven mats.

In addition, kenaf bast fibers have the potential to be used as a reinforcing fiber in thermoplastic composites, due to its properties which exhibit a superior toughness and a high aspect ratio in comparison to other fibers. Based on the study made by Karnani R *et al*. [9], a single fiber of kenaf can have a tensile strength and modulus as high as 11.9 GPa and 60 GPa, respectively. Study by Giuseppe *et al*. [15] has showed the potential of kenaf as reinforcing material by showing the comparison of mechanical properties of kenaf compared to other fiber commonly used in composite systems, as shown in Table 2.1.

Based on the findings, kenaf fiber was chosen among other natural fiber such as henequen, pineapple, bananas, and hemp as the reinforcement material to be used in this project.

Table 2.1: Characteristic values for the density, diameters and mechanical properties of (natural) plant and synthetic fiber [15].

Fibers	**Type of fibers**	**Density (g/cm^3)**	**Tensile Strength (MPa)**	**Young Modulus (GPa)**	**Moisture Absorption (%)**
Kenaf	Natural fiber	1.2 – 1.4	930	53	17
Flax	Natural fiber	1.5	345 – 1500	27.6	12
Cotton	Natural fiber	1.5 – 1.6	287 – 800	5.5 – 12.6	8.5
E – Glass	Synthetic fiber	2.55	3400	73	N/A
Carbon	Synthetic fiber	1.78	3400 – 4800	240 425	N/A

2.2.2 High Density Polyethylene (HDPE)

HDPE is commonly used to make plastic bags and refillable plastic bottles as shown in Figure 2.2. The other applications are chemical resistance piping system, corrosion protection for steel pipelines, and water pipes for domestic water supply and agricultural process. In addition, recycled HDPE is used to manufacture lawn and garden products, buckets, office products and automobile parts [16, 17].

HDPE plastic has several properties that make it ideal as a packaging and manufacturing product. It acts as an effective barrier against moisture and oxygen. It resists insects, rot and other chemicals. It is easily recyclable and can be used again and again. Recycled HDPE creates no harmful emissions during the production or during the usage. HDPE leaks no toxic chemicals into the soil or water [16]. Some properties of HDPE are shown in Table 2.2.

HDPE is likely to be produced by blow moulding techniques. Additionally, HDPE is applicable to be used as matrix in fiber reinforced composites. It is available in pellets and granules form and can be fabricated by using various types of moulding techniques due to high melt flow index it has which is 18 g/10min. Therefore, HDPE is been chosen as the matrix.

Figure 2.2: Application of HDPE in oil bottle [16].

Table 2.2: Properties of HDPE [18].

Mechanical properties	**Value**	**Unit**
Young's modulus	600-1400	MPa
Tensile strength	20-32	MPa
Flexural Modulus	700-800	MPa
Bending strength	20-45	MPa
Physical properties	**Value**	**Unit**
Melting temperature	108-134	^{o}C
Density	940-965	kg/m3

2.3 HDPE composites and kenaf fiber reinforced polymer

2.3.1 HDPE composites

The mechanical properties of HDPE composite have been studied for many years. Herrera-Franco *et al*. [19] studied the degree of fiber-matrix adhesion and its effect on the mechanical reinforcement of short henequen fibers-filled polyethylene matrix. In the experiment, several surface treatment were used which included alkali treatment, silane coupling agent, and pre-impregnation process of HDPE/xylene solution. An investigation of tensile, flexural and shear properties of the composites was made. The results of the mechanical properties of HDPE/ henequen-fiber composite with different types of surface treatments are shown in Figure 2.3 and the nomenclature of the figure are shown in Table 2.3.

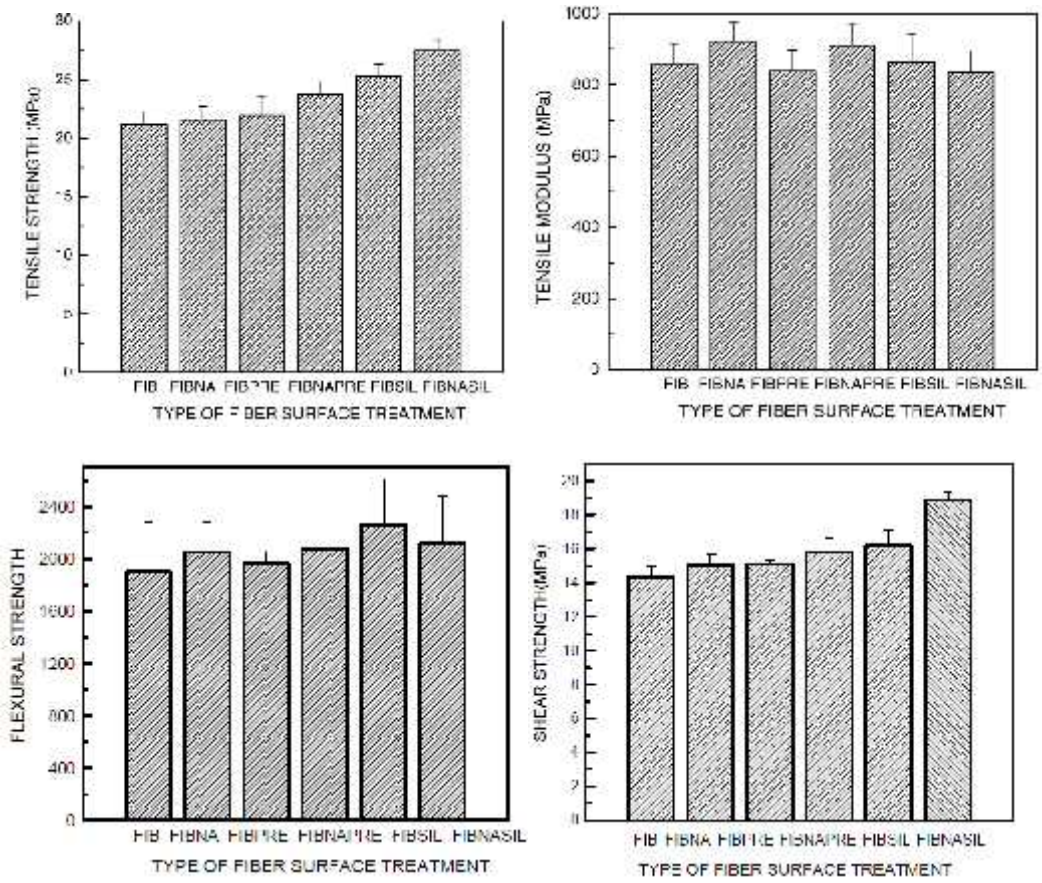


Figure 2.3: Mechanical properties of HDPE/ henequen-fiber (80:20 v/v) composite with different types of surface treatments. [19].

Table 2.3: Nomenclature for Figure 2.3 [19].

Keyword	**Description**
FIB	Fiber without treatment
FIBNA	Fiber treated with a NaOH aqueous solution
FIBPRE	Fiber pre-impregnated with dissolved HDPE
FIBNAPRE	Fiber treated with a NaOH aqueous solution and then impregnated with dissolved HDPE
FIBSIL	Fiber treated with a silane coupling agent
FIBNASIL	Fiber treated with a NaOH aqueous solution and then with a silane coupling agent

From Herrera-Franco *et al*. [19] research, the silane treatment and the matrix-resin pre-impregnation process of the fiber produced a significant increase in tensile strength, while the tensile modulus remained relatively unaffected. The increase in tensile strength was only possible when the henequen fibers were treated first with an alkaline solution. It was also shown that the silane treatment produced a significant increase in flexural strength while the flexural modulus also remained relatively unaffected.

2.3.2 Kenaf fiber reinforced polymer

The study of PLA/kenaf composite was done by Shinji Ochi [10] , and it stated that the composite exhibited biodegradability properties, increased in tensile strength which was 223.3 MPa for 70% volume fraction of fibers compared to neat PLA, which was 32.5 MPa. The strength and weight decreased to 91% and 38%, respectively, after composting for 4 weeks. The biodegradability of the composite was confirmed experimentally. Data of his experiments are tabulated in Table 2.4.

Table 2.4: Comparison of theoretical and experimental value of tensile strength of volume fraction of kenaf fiber in PLA composites [10].

Volume fraction of kenaf fibers (%)	Theoretical Strength (MPa)	Experimental Strength (MPa)	Experiment / Theory (%)
30	178.2	130.5	73.1
50	297.0	210.9	71.0
70	415.8	223.3	53.7

Study made by Nishino *et al*. [6] presented the effects of fiber content to the mechanical properties of kenaf fibers reinforced PLLA composite. The optimum tensile properties and Young's modulus were dictated by the volume of reinforcing fiber used for the composites as shown in Figure 2.4. The maximum value of tensile strength and Young modulus were achieved at volume fraction of fiber 70%. From both studies, we can conclude that kenaf fiber is quite effective when being reinforced with polymer matrix. For this project, it is predicted that the properties of kenaf fiber reinforced with HDPE will be improved similar to PLA/kenaf fiber composite and PLLA/kenaf fiber composite properties.

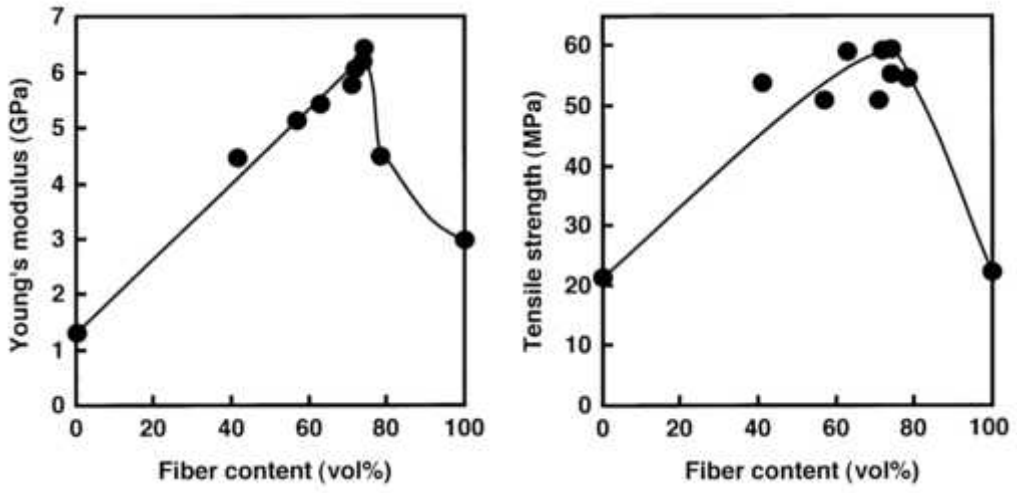


Figure 2.4: Relationship between Young's Modulus, the tensile strength, and the kenaf fiber content of PLLA/kenaf composite [6].

2.4 Effects of compatibilizer on mechanical properties

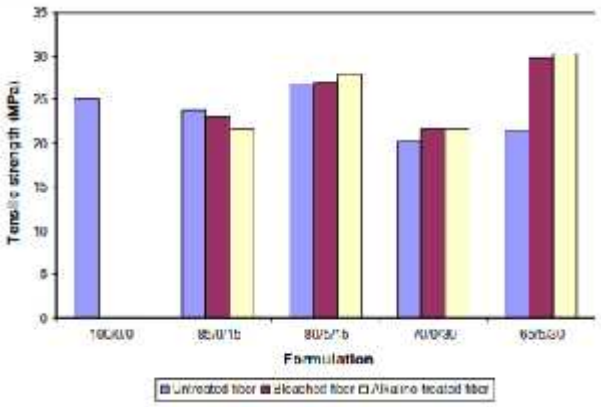


Figure 2.5: Effect of coupling agent concentration on tensile strength of PP composites with 10% w/t coir fibre [20]

Properties of flax/polypropylene (PP) composites were studied by Fuqua *et al.* [20]. Tensile properties of treated (alkali and bleached) and untreated flax fiber without compatibilizer (maleic anhydride grafted polypropylene or MAPP) were compared to the composites with compatibilizer in PP composites. As shown in Figure 2.5, 5% of MAPP is found to be the optimum amount of compatibilizer to get the improvement on tensile strength. Therefore, 5% of MAPP was chosen for this project.

2.5 Compression moulding

Method of fabrication is one of the factors that influence the mechanical properties of the composite. A study by Zampaloni *et al*. [8] on the discussion of manufacturing problems and solution on kenaf/polypropylene composites concluded that the optimal fabrication method to fabricate the composites into sheet form is by compression moulding techniques. The layered sifting of a microfine polypropylene powder and kenaf chopped fiber has proven as the most optimal ways of fabrication. The results of tensile properties of the composites are compared to other natural composites, and the composites is proven to provide tensile strength that is very similar to flax/PP and hemp/PP and give higher strength than coir/PP and sisal/PP. thus, compression moulding method is used as it is also suitable to fabricate kenaf continuous long fiber.

2.6 Theoretical calculation

The theoretical calculation as shown in equation 1 and 2 is applied to determine the expecting result (ideal state) of the composites to be made [16]. The results will be compared to the experimental result of POM/kenaf mechanical properties.

$$\sigma_c = \sigma_f V_f + \sigma_m V_m \qquad \textit{Eqn.1}$$

$$E_c = E_f V_f + E_m V_m \qquad \textit{Eqn.2}$$

where:

σ_c = Tensile strength of composite

σ_m = Tensile strength of matrix

σ_f = Tensile strength of fiber

E_c = Tensile modulus of composite

E_m = Tensile modulus of matrix

E_f = Tensile modulus of fiber

V_m = Volume fraction of matrix

V_f = Volume fraction of fiber

The calculation is being applied up to 60% of volume fraction of kenaf fiber which is the maximum of volume fraction can be applied in the composites. Based on the study made by Nishino *et al.* [6], when fiber fraction increased more than 60%, the mechanical properties reduced due to the insufficient matrix filling of the matrix resin.

CHAPTER 3

METHODOLOGY

3.1 Project Activities

The procedures to achieve the objectives of the project are shown in the flow chart process in Figure 3.1. The step-by-step explanation of project work to be done is shown clearly in the flow chart below.

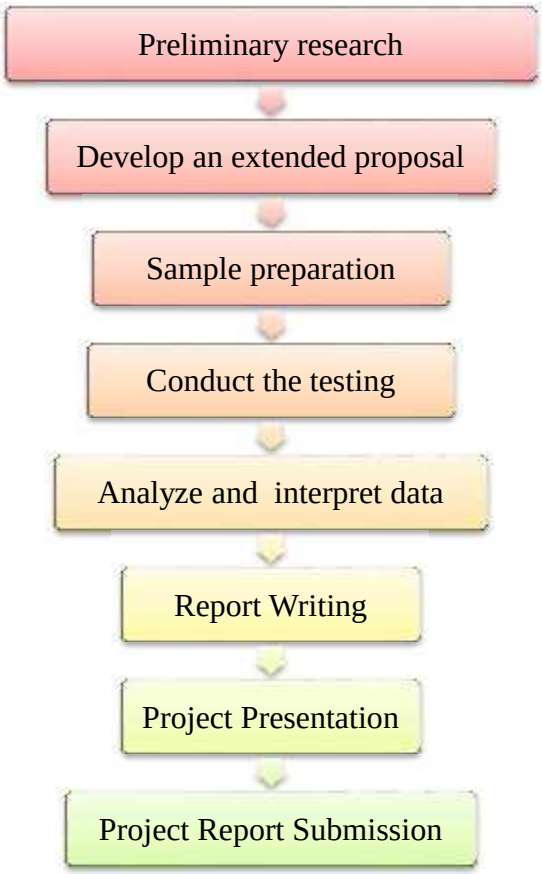


Figure 3.1: Flow chart of activities for the projects.

The project was started by doing a preliminary research and studies on the topic selection. The information was collected from many sources such as journal articles, books, newspapers, and internet. From the studies, a better understanding on the topic was achieved. Several factors and limitations that could influence the results of the studies were identified. Then, the samples were fabricated based on the parameter and method chosen. Material testing was conducted based on American Standard for Testing and Material (ASTM). After that, the results were analyzed and discussed. Scanning electron micrograph provided the support for the discussion. The documentation of the study was compiled after the project was completed.

3.1.1 Sample preparation

The tool and equipment required were identified and setup according to the lab procedure. Table 3.1 shows the tool and equipment used for the project.

Table 3.1: List of equipment used in the project.

Diagrams	Equipment	Functions
	**Compression Machine** Manufacturer: CARVER INC Model: CMG3OH-15-CPX Compression Force: 30 tons	To fabricate specimens of HDPE/kenaf composites by using compression moulding.

Diagrams	Equipment	Functions
	**Electronic Balance / Weighing Machine** Manufacturer: Mettler Toledo Model: Balance Max 16000g	To weigh the sample with high precision
	**Universal Tensile Machine** Manufacturer: AMATEK INC Model: LLOYD LR Series (5 kN)	To perform the tensile test and 3-points bending test on the specimens
	**Oven** Manufacturer: Carbolite 450 Model: LHT 450	To remove moisture from kenaf fiber by drying the fiber at certain temperature.
	**Tensile Mould** Manufacturer: Technic Engineering	To fabricate tensile dog bone shaped specimens according to standard ASTM D 638
	**Flexural Mould** Manufacturer: Universiti Teknologi Petronas	To fabricate flexural rectangular shaped specimens according to standard ASTM D 790

Figure 3.2: HDPE pellets

The material used to fabricate the composites was HDPE polymer as shown in Figure 3.2. HDPE pellets were obtained from PT. TITAN Petrokimia Nusantara (Banten, Indonesia). Its melt flow index is 18 g/10 min at 190°C with a density of 950 kg/cm^3 and melting temperature of 130°C.

Figure 3.3: Preparation of kenaf fiber.

For the reinforcement, kenaf fiber was chosen. Kenaf yarn long fiber from Innovative Pultrusion Sdn Bhd (India) was used in this experiment. The preparation of kenaf fiber is shown in Figure 3.3. Chemical treatment was applied on the kenaf fiber before it was used in the experiment. The fiber was soaked in the sodium hydroxide solution (NaOH) of 6% concentration for 24 hours. Then, the fiber were washed with distilled water for 7 times and allowed to dry in oven at 50°C for 8 hours. Lastly, the fiber was stored in container to control the moisture content.

Figure 3.4: MAPP Fusabond resin P-613

An anhydride modified polypropylene (MAPP), Fusabond resin P 613 from DuPont Packaging & Industrial Polymers Malaysia was used in the experiment. Figure 3.4 shows the MAPP. It has 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.

After the equipment and materials are prepared, the project was proceed with the preparation of HDPE/kenaf composites. Neat HDPE, HDPE/kenaf composites with and without 5% of compatibilizer were prepared. The compositions of samples produced are shown in Table 3.2. There were 3 main steps involved to produce the composites. The procedures are explained in details at the next page.

Table 3.2: Compositions of specimens produced.

Samples	Matrix (wt. %)	Reinforcement (wt. %)	Coupling Agent (wt. %)
Neat HDPE	100	-	-
HDPE/Kenaf	80	20	-
	70	30	-
	60	40	-
HDPE/Kenaf with coupling agent	80	20	5
	70	30	5
	60	40	5

Step 1: Preparation of HDPE layer

The preparation of HDPE layer is shown in Figure 3.5. The procedure is explained below.

Figure3.5: Preparation of HDPE layer.

1. 8 g of HDPE pellet was weighed in the electronic weighing machine.
2. HDPE pellet was charged into the mould cavity.
3. Compression machine was set at 160°C and 12.5 ton pressure.
4. The mould was preheated for 10 minutes.
5. The mould was compress and heat for another 15 minutes.
6. The mould was cooled by using air until the temperature reached 90°C - 80°C.
7. HDPE layer was removed from the mould.

Step 2: Preparation of kenaf fiber

The procedure for preparation of kenaf fiber are explained below.

1. Kenaf fiber was cut into desired length of tensile dog-bone shape and flexural bending-rectangular shape.
2. The fiber was weighed according to the weight fraction desired.

Step 3: Preparation of composite HDPE/kenaf

Table 3.3 shows the weight of trial specimens and the target weight of the actual samples to be produced. The preparation of composite HDPE/kenaf is shown in Figure 3.6. The procedure is explained in the next page.

Table 3.3: Targeted weight of composite.

Composition (%)	Weight-trial (composite) (g)	Weight-target (composite) (g)
80/20	9.98	10
70/30	11.02	11
60/40	12.05	12
80/20 w/c	10.03	10
70/30 w/c	10.98	11
60/40 w/c	11.99	12

Figure 3.6: Preparation of HDPE/kenaf composites with & without compatibilizer.

1. The weighed composite was done according to the trial specimens. The assumption of the composite's weight was proportion to 100% of weight fraction.
2. 2 layers of HDPE matrix were prepared.
3. 20% wt.% of kenaf fiber was weighted. The weight was fixed for the 5 specimens.
4. Layer of HDPE matrix was put into the mould and kenaf fiber was sandwiched between the bottom and top layers of the HDPE matrix.
5. Compression machine was set at 200°C and 12.5 ton pressure.
6. The mould was preheated for 15 minutes.
7. The mould was compressed and heated for another 20 minutes.
8. The mould was cooled by using air until the temperature reached 90^0C - 80^0C.
9. Specimens were removed from the mould after they can be handled.

10. Steps 1 to 9 were repeated for different compositions of the fiber in the composites.
11. Steps 1to10 were repeated to prepared specimens with coupling agent. The compatibilizer was placed in between the kenaf fiber and HDPE matrix
12. Samples produced are shown in Figure 3.7. They were kept in a container to control the moisture absorption.

Figure 3.7: Samples of HDPE/kenaf composites

3.1.2 Material Testing

Material testing was done to determine the effects of the tensile and flexural properties on the specimens. Tensile test was conducted on five specimens at room temperature using the Universal Testing Machine. The specimens were tested according to ASTM D638 Type 1 dimension [22] as shown in Figure 3.8. The specimen dimensions for tensile test are shown in Table 2.4.

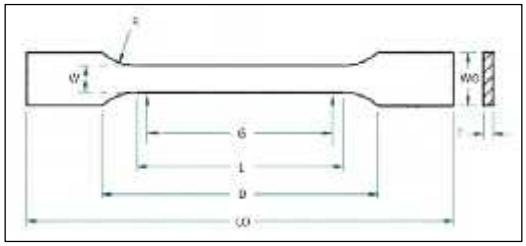


Figure 3.8: Type 1 dimension tensile specimen.

Table 3.4: Specimen dimensions for tensile test [20].

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

Meanwhile, 3-points bending test was conducted on five specimens at room temperature using Universal Testing Machine. The specimens are tested according to ASTM standards D790 [23]. 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 3.9.

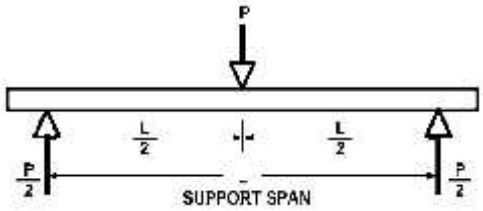
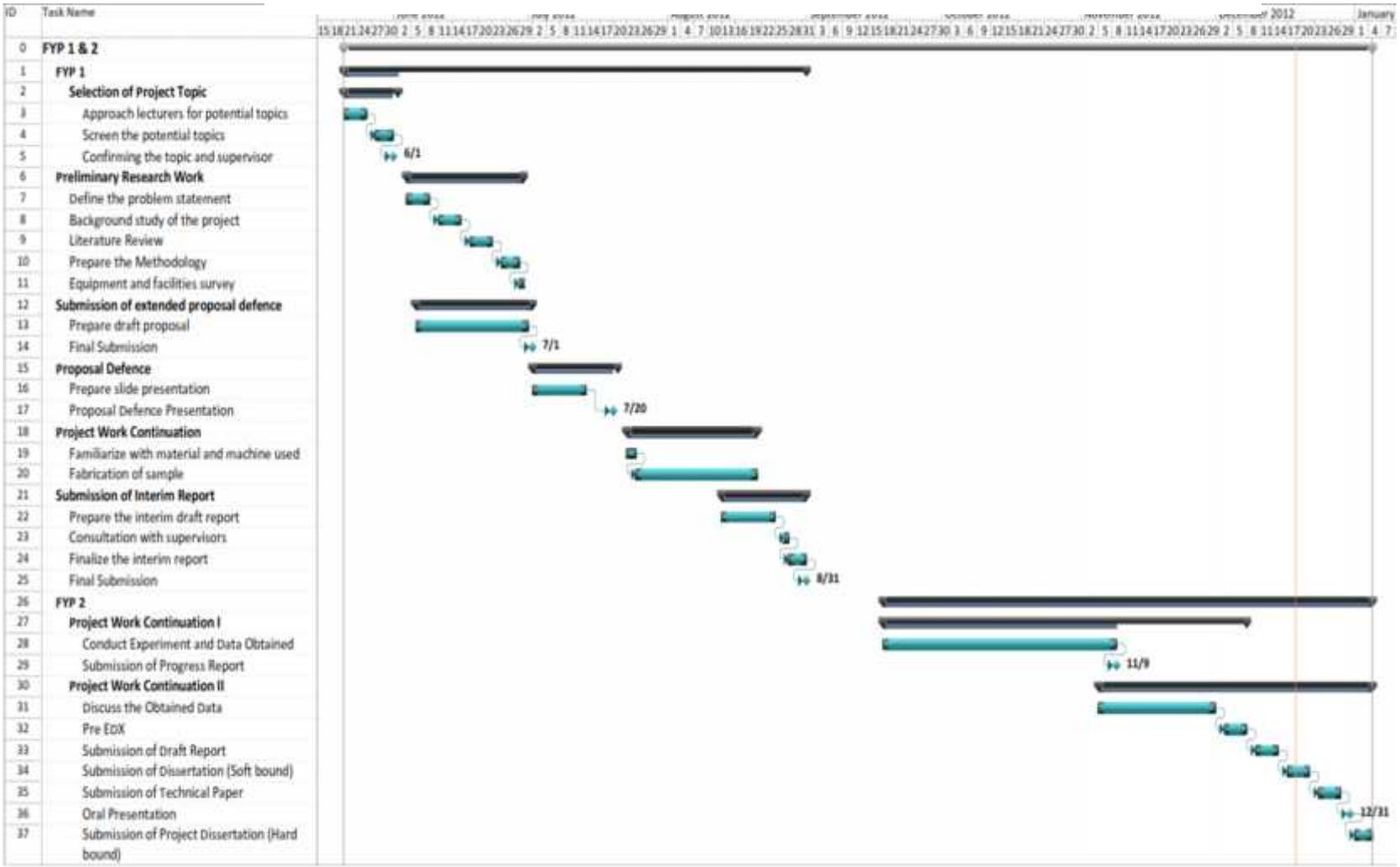


Figure 3.9: Loading diagram of 3-points bending test [21]

3.2 Gantt chart, key milestones, and project activities

The Gantt chart, key milestones, and project activities are presented in the Table 3.5 for FYP I and FYP II. The planning of this project was listed in the Gantt chart with reference to the duration of the activities while key milestones indicated the important events of project.

Table 3.5: Gantt chart, project activities, and key milestones of the project for FYP I and II



3.3 Design calculation formula

The formula to calculate the theoretical value of the tensile properties was taken from Jones [21]. The theoretical results show the ideal cases that could be obtained. The formulas for theoretical calculation are:

$$\sigma_c = \sigma_f V_f + \sigma_n V_n \qquad \textit{Eqn.1}$$

$$E_c = E_f V_f + E_n V_n \qquad \textit{Eqn.2}$$

where:

σ_c	= Tensile strength of composite	E_c	= Tensile modulus of composite
σ_m	= Tensile strength of matrix	E_m	= Tensile modulus of matrix
σ_f	= Tensile strength of fiber	E_f	= Tensile modulus of fiber
V_m	= Volume fraction of matrix	V_f	= Volume fraction of fiber

Several assumptions were made for the theoretical results as shown below:

- No voids in the composites.
- Perfect bonding between matrix-fiber interphase.

3.4 Sample calculation

The sample calculation for the specimen is shown below:

Example: 1. Volume fraction of fiber = 0.3

2. Volume fraction of matrix = 0.7

Tensile strength of composites, σ_c

$\sigma_c = \sigma_f V_f + \sigma_m V_m$

$\sigma_c = (930MPa)(0.3) + (23MPa)(0.7)$

$\sigma_c = 295.1MPa$

Elastic modulus of composite, E_c

$E_c = E_f V_f + E_m V_m$

$E_c = (53GPa)(0.3) + (0.6GPa)(0.7)$

$E_c = 16.32GPa$

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Theoretical results and discussions

The theoretical results of the tensile properties are shown in Figures 4.1and 4.2. The tabulated data of theoretical results for tensile properties are shown in Table A-1 (Appendices). As expected, the tensile properties increased with the increments of fiber content. This is because the calculations are based on the ideal cases. Hence, lower tensile properties are expected in the experimental results due to the existence of void content and lack of interfacial bonding.

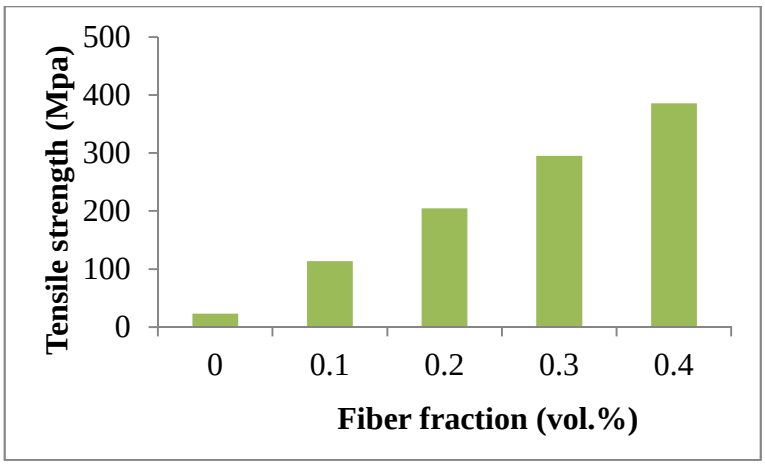


Figure 4.1: Tensile strength of composites with respect to fiber content.

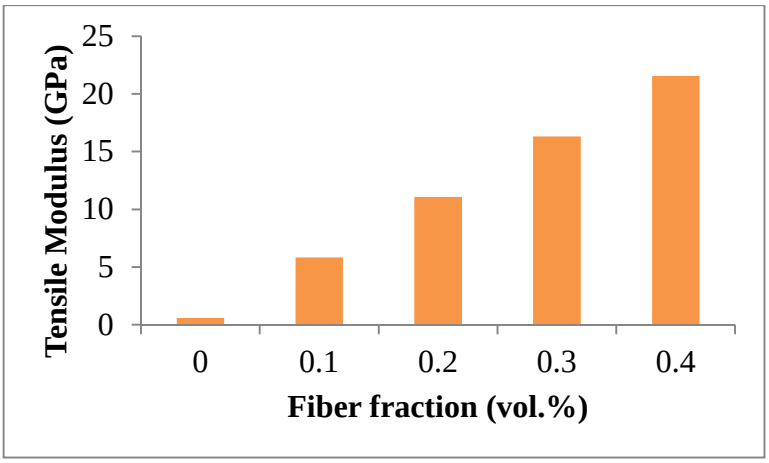


Figure 4.2: Tensile modulus of composites with respect to fiber content.

4.2 Experimental results and discussions

Figures 4.3 and 4.4 show the tensile strengths and moduli of the tested specimens. An increasing trend was observed as kenaf fiber was increased from 20 to 30 wt.%. Conversely, a decreasing trend was observed from 30 to 40 wt.% of kenaf content, suggesting that the best composition for tensile properties was 70/30. Increments up to 195% and 340% were achieved for tensile strength and modulus, respectively, compared to neat HDPE.

From the results, it can be concluded that the percentage of load carried by the fibers increases with respect to the increment of fiber content and the optimum value of fiber content that can be embedded in the matrix is 30%. When the ratio goes beyond 30%, the strength will decrease due to insufficient filling of the matrix resin in the composites, which limited the ability to wet and infiltrate the kenaf fibers.

However, specimens with compatibilizer did not improve their tensile properties compared to their respective compositions without compatibilizer except for 60/40 wt.%. this may be due to the bigger gap of matrix-fiber ratio leads to the lack of chances for the compatibilizer to sit between matrix and reinforcement since the compression moulding limits the movement of the molten matrix and compatibilizer. Similar ratio of matrix and reinforcement may give better chance for the compatibilizer to be in between matrix and reinforcement, resulting in better

interfacial bonding. The improvement of tensile strength and modulus for 60/40 wt.% were 214% and 347% respectively, compared to neat HDPE. The tabulated data of tensile properties are shown in Table A-3 and A-4 (Appendices).

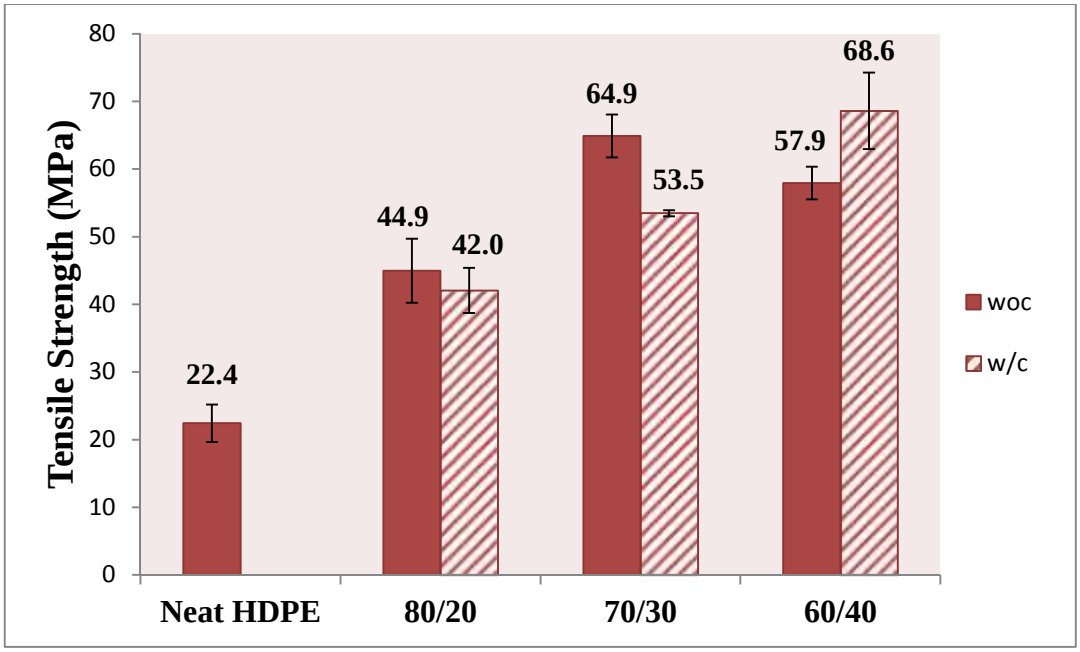


Figure 4.3: Tensile strengths of HDPE/kenaf with and without compatibilizer by wt.%.

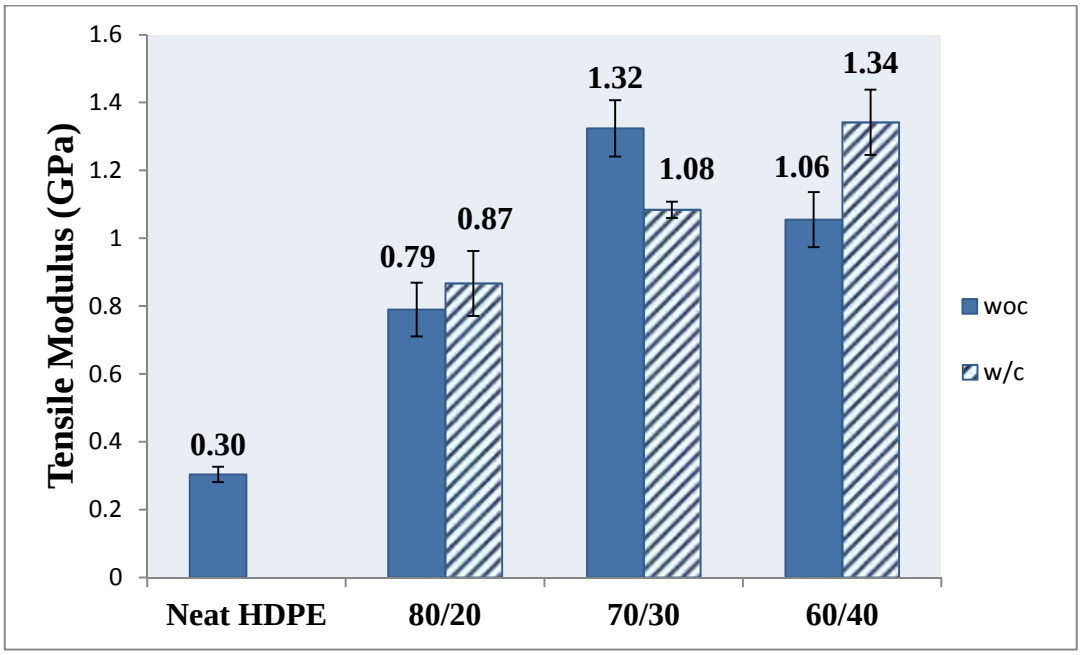


Figure 4.4: Tensile moduli of HDPE/kenaf with and without compatibilizer by wt.%.

The results of flexural strengths and moduli are shown in Figure 4.5 and 4.6. Similar trends as tensile strengths and moduli are recorded for both flexural strengths and moduli, respectively. Flexural strengths of the specimens and moduli improved 100% and 163% for 70/30 wt.% compared to neat HDPE, respectively. The addition of compatibilizer on the composites showed adverse effects compared to their respective compositions without compatibilizer except for 60/40 wt.%. The maximum increments achieved by the composite with compatibilizer were 79% and 130% for flexural strengths and moduli, respectively, compared to neat HDPE. Similar explanation given for tensile properties should relevant to the flexural properties as well.

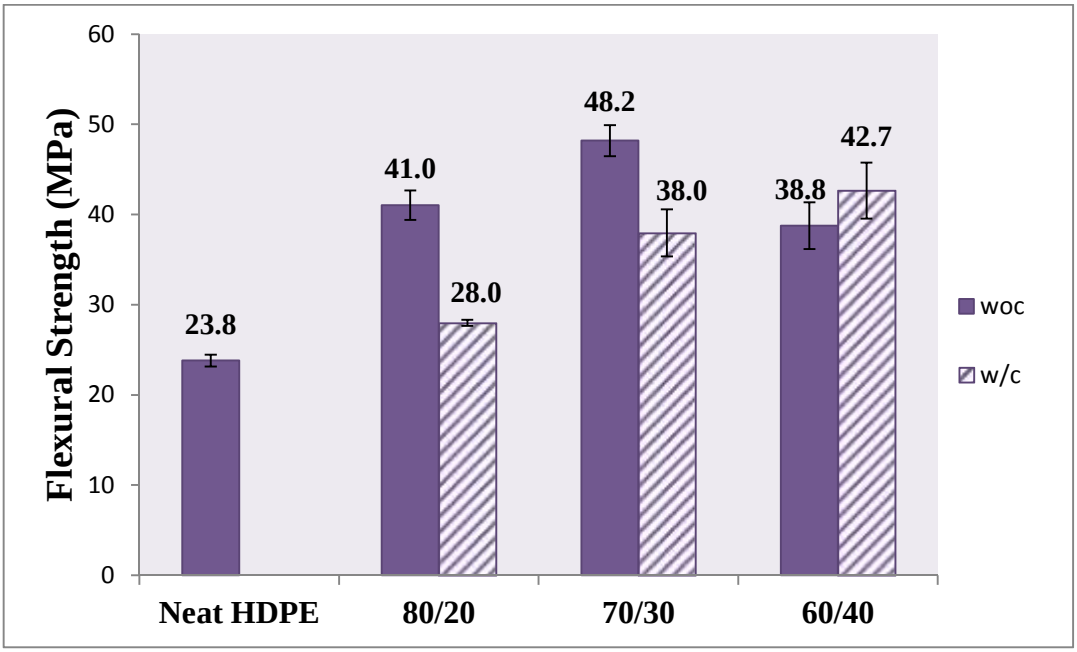


Figure 4.5: Flexural strengths of HDPE/kenaf with and without compatibilizer by wt.%.

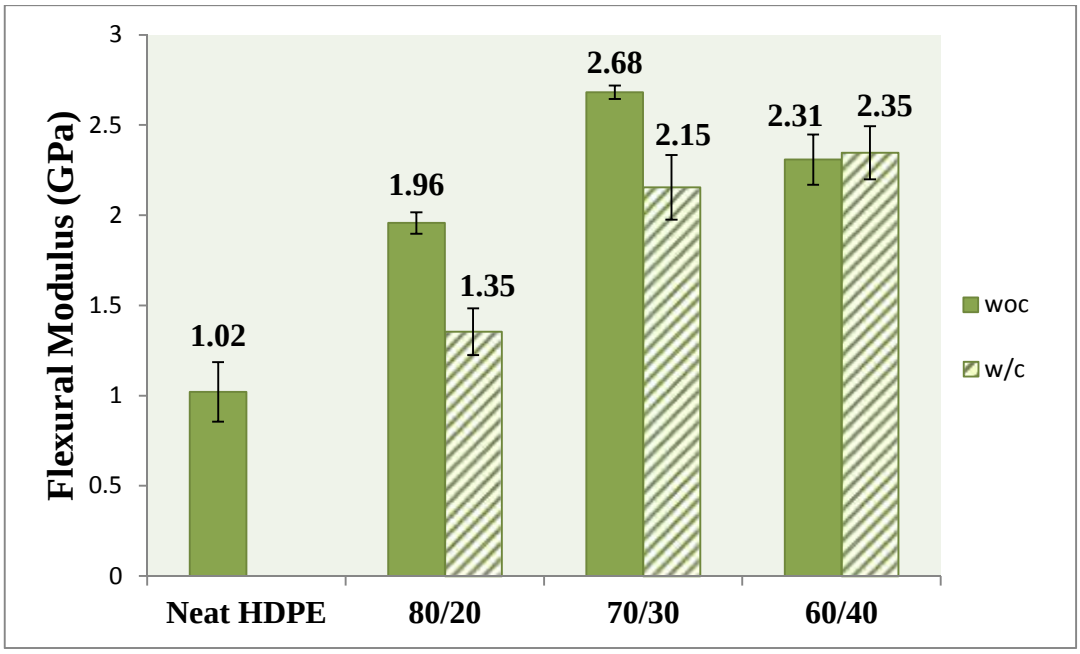


Figure 4.6: Flexural moduli of HDPE/kenaf with and without compatibilizer by wt.%.

The morphological characteristic of the samples were studied using FESEM. The images of FESEM are shown in Figure 4.7, 4.8 and 4.9. Figure 4.7 shows fibers pull-out suggesting poor bonding between matrix and fiber. Meanwhile, the addition of compatibilizer suggest a strong interfacial bonding between the matrix and the fiber where the fiber is not loose from the matrix even after the fiber has been pulled out as shown in Figure 4.8. Similar results are shown in Figure 4.9 where the matrix fully coated and bind to the fiber wall, indicating that the compatibilizer has improved the interfacial bonding of matrix and fiber.

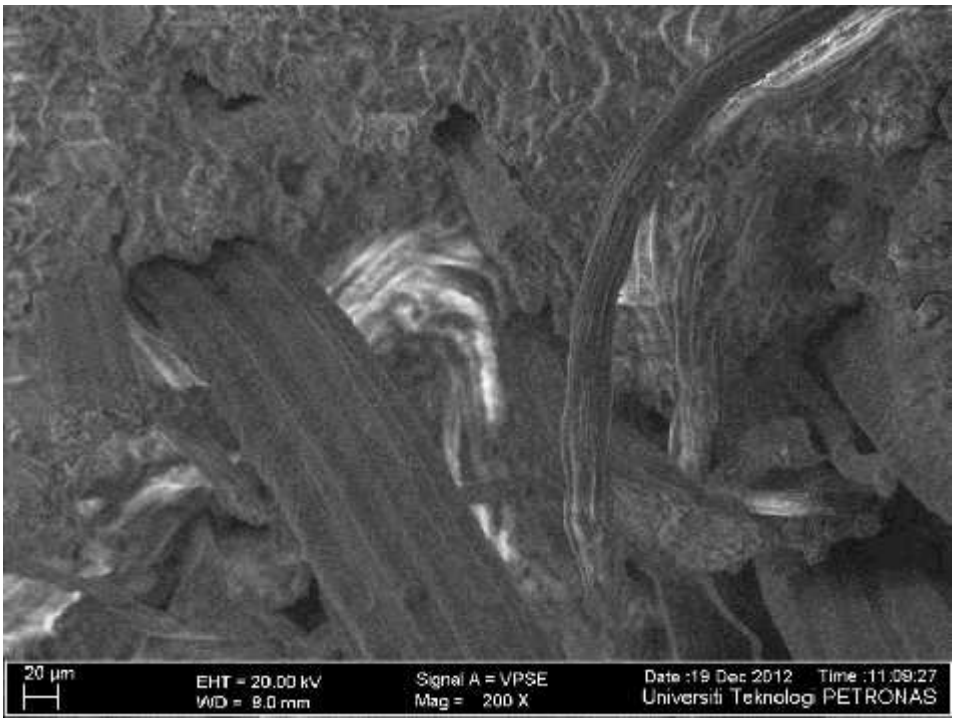


Figure 4.7: FESEM images of 60/40 wt.% HDPE/kenaf composites without compatibilizer.

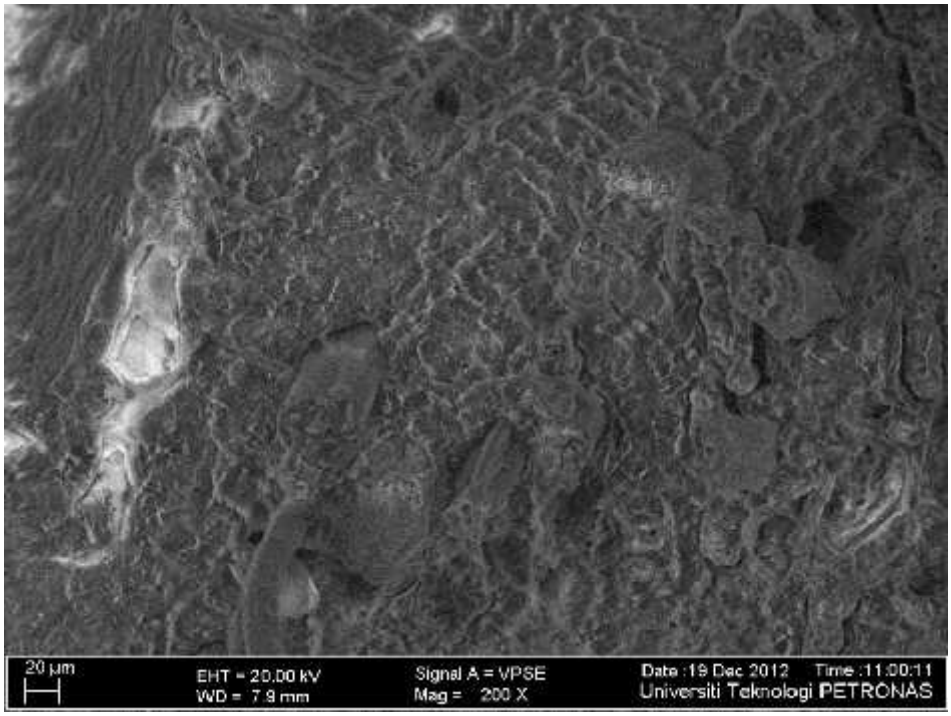


Figure 4.8: FESEM images of 60/40 wt.% HDPE/kenaf composites with compatibilizer.

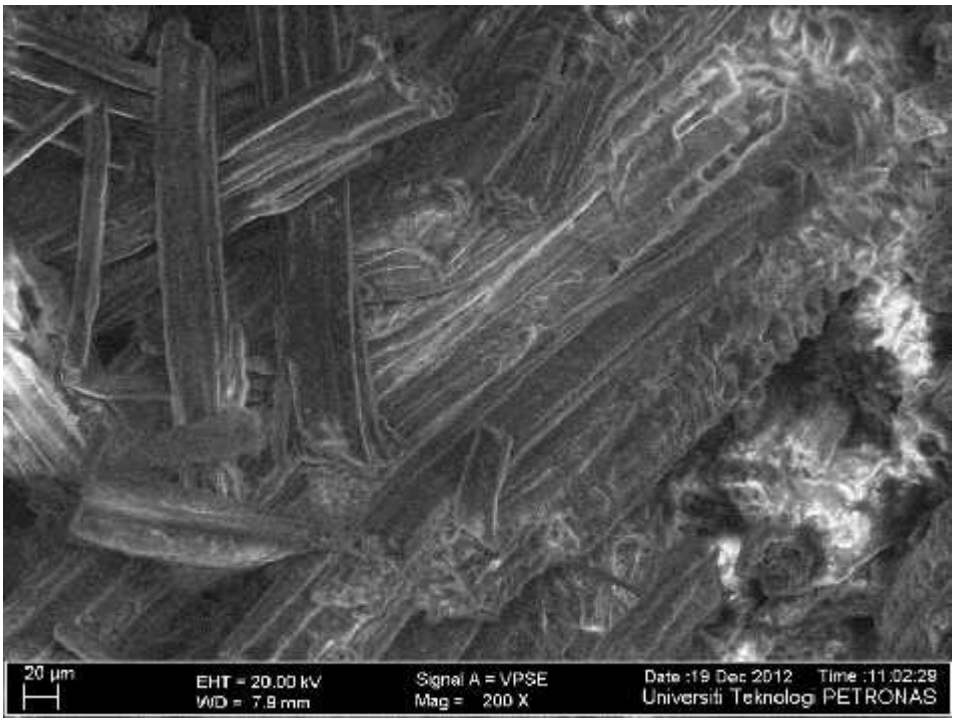


Figure 4.9: FESEM images of 60/40 wt.% HDPE/kenaf composites with compatibilizer.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The objectives of this project were achieved. Tensile and flexural properties of HDPE/kenaf composites with and without compatibilizer had been investigated. HDPE/kenaf composites of 60/40 with compatibilizer had shown significant improvement in tensile strengths and moduli, which were 214% and 347% compared to neat HDPE, respectively. Meanwhile, the composites without compatibilizer had shown significant improvement in flexural strengths and moduli with 100% and 163% compared to neat HDPE, respectively. FESEM images show the interfacial bondings of matrix-fiber were improved when compatibilizer was applied.

5.2 Recommendation

As for the future works, it is recommended to improve the method of fabrication which can provide a good mixing process for the compatibilizer with matrix and fiber. The compatibilizer should be crushed into smaller pieces or in the form of powder. Then, the compatibilizer can be mixed with the fibers so that it will have a better chance to sit between the fibers. Hence, it can lead to higher possibility of reaction between compatibilizer to the interfacial bonding of matrix-fiber, resulting improvement of mechanical properties of the composites.

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APPENDICES

Table A-1: Theoretical results of various compositions

Volume Fraction of Matrix (%)	Volume Fraction of Fiber (%)	Tensile Strength (MPa)	Elastic Modulus (GPa)
100	0	23.0	0.6
80	20	204.4	11.08
70	30	295.1	16.32
60	40	385.8	21.56

Table A-2: Tensile strengths of HDPE/kenaf with and without compatibilizer by wt.%.

Specimens	Samples	Average	Std Deviation
Neat HDPE	19.257	22.416	2.753
	23.688		
	24.303		
80/20	50.000	44.949	4.724
	40.639		
	44.208		
70/30	66.044	64.885	3.151
	67.291		
	61.319		
60/40	57.728	57.935	2.426
	55.619		
	60.457		
80/20/C	38.509	42.047	3.317
	42.546		
	45.086		
70/30/C	53.676	53.473	0.455
	53.791		
	52.952		
60/40/C	59.593	68.588	5.659
	75.121		
	61.915		

Table A-3: Tensile moduli of HDPE/kenaf with and without compatibilizer by wt.%.

Specimens	Samples	Average	Std Deviation
Neat HDPE	326.737	0.304	0.023
	305.890		
	281.428		
80/20	900.524	0.790	0.079
	725.100		
	744.647		
70/30	1415.307	1.324	0.083
	1252.409		
	1304.338		
60/40	972.303	1.055	0.081
	1134.337		
	1061.277		
80/20/C	771.682	0.867	0.096
	865.960		
	964.305		
70/30/C	1110.254	1.084	0.024
	1080.547		
	1061.630		
60/40/C	1246.045	1.342	0.096
	1438.060		
	1233.434		

Table A-4: Flexural strengths of HDPE/kenaf with and without compatibilizer by wt.%.

Specimens	Samples	Average	Std Deviation
Neat HDPE	23.150	23.802	0.660
	23.788		
	24.469		
80/20	16.474	41.027	1.629
	13.012		
	15.915		
70/30	18.725	48.192	1.726
	11.810		
	14.045		
60/40	10.311	38.760	2.593
	11.262		
	10.370		
80/20/C	10.885	27.982	0.338
	11.636		
	10.659		
70/30/C	11.899	37.951	2.603
	15.391		
	12.914		
60/40/C	10.697	42.654	3.115
	10.717		
	8.756		

Table A-5: Flexural moduli of HDPE/kenaf with and without compatibilizer by wt.%

Specimens	Samples	Average	Std Deviation
Neat HDPE	1211.445	1.020	0.165
	912.302		
	937.382		
80/20	1954.428	1.957	0.059
	1609.028		
	1900.339		
70/30	2639.89443	2.682	0.037
	2699.63041		
	2236.27518		
60/40	2150.06945	2.308	0.139
	1999.20042		
	1761.74591		
80/20/C	1505.98316	1.354	0.13
	1279.29321		
	904.017807		
70/30/C	1947.85972	2.154	0.179
	1781.40793		
	1576.08898		
60/40/C	2483.885	2.346	0.147
	1873.109		
	2364.484		