TENSILE AND FLEXURAL PROPERTIES OF COMMINGLED KENAF/PET REINFORCED POLYPROPYLENE HYBRID COMPOSITES

By

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

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CERTIFICATION OF APPROVAL

TENSILE AND FLEXURAL PROPERTIES OF COMMINGLED KENAF/PET REINFORCED POLYPROPYLENE HYBRID COMPOSITES

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A project dissertation submitted to the
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Approved by,

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CERTIFICATION OF ORIGINALITY

With this I clarify that this report was originally produced except the specified references and acknowledgement and the original work contained herein have not been undertaken or done by unspecified sources or persons.

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ABSTRACT

Commingled hybrid composite has a potential to improve further the physical and mechanical properties. However, very limited studies have been done on commingled hybrid composite. Therefore, this project was proposed to study the effects of commingled hybrid composite of PP/kenaf/PET on tensile and flexural properties. The PP/kenaf/PET composite was manufactured by compression moulding. Due to the constraint of mould cavity, only two compositions were produced i.e. 85/10/5 and 85/5/10 (PP/kenaf/PET) wt.%. Tensile strengths of commingled 85/5/10 were increased by 48% and 13% compared to neat PP and non-commingled 85/5/10, respectively. However, commingled hybrid composite showed an adverse effect to tensile modulus and flexural properties compared to that of non-commingled composite.

ACKNOWLEDGMENT

In the name of Allah, the Most Gracious, the Most Merciful. Praise to Him the Almighty that in his will and given strength, I managed to complete this Final Year Project for the Mechanical Engineering Department, Universiti Teknologi PETRONAS.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Hybrid composites are materials made by combining two or more types of fibers in a matrix [1]. Hybrid composites have long taken the attention of many researchers as a way to enhance mechanical properties of composites. Hybrid composites provide combination of properties such as tensile modulus, compressive strength and impact strength which cannot be realized in composite materials [2]. By mixing two or more types of fiber in a resin to form a hybrid composite, it may be possible to create a material that combines combined advantages of the individual components and simultaneously mitigates the less desirable qualities [3].

Many studies were done on reinforcing natural fiber like kenaf with others synthetic fiber to thermoplastics polymer [4-6]. However, the study have suggested that the main factor that limits the mechanical properties of natural fiber reinforced thermoplastic composites was the bad interfacial bonding between the reinforcement and the matrix. This incompability cause ineffective load transfer between the reinforcing material and matrix. Various options were suggested in order to achieve the compability between the reinforcement and matrix including surface treatment and use of compatibilizers but shown insignificant results.

So, other alternative option was suggested to improve the bonding between the matrix and the fiber. A technique so called commingled was introduced as potential process to improve the interfacial bonding of fiber and matrix but very limited study was done. Commingled is a process where the natural fiber and the synthetic fiber will twisted together to become like one strand fiber [7]. So, in this research, the effect of commingled kenaf/PET reinforced PP composites on the tensile and flexural properties are investigated.

1.2 Problem Statement

Commingled is one of process used in fabricating hybrid composites material where the reinforcement fibers are twisting together to become like one strand of fiber. This process has a great potential in achieving a better mechanical properties of hybrid composites [7]. But, very limited studies were done on mechanical performance of commingled kenaf/PET reinforced PP hybrid composites. Therefore, this project was proposed to investigate the potential benefits of commingled process in hybrid composite. The applications of commingled hybrid composite could be broaden since the performance of the composite is expected to improve significantly.

1.3 Objective

The objective of this project is to study the effects of commingled hybrid composite of PP/kenaf/PET on tensile and flexural properties.

1.4 Scope of Study

A commercial type of PP was used as the matrix with continuous kenaf and PET fibers. The reinforcements, kenaf and PET fibers, were manually commingled. The hybrid composite specimens were prepared using compression moulding method. Due to the constraint of mould cavity, only two compositions were considered i.e. 85/10/5 and 85/5/10 (PP/kenaf/PET) wt.%.

CHAPTER 2

LITERATURE REVIEW

2.1 Kenaf and Polyethylene Terephthalate (PET) Fibers

Since a decade ago, kenaf has been used as a raw material in pulp and paper industries, as non-woven mats in the automotive industry and fiberboard as shown in Figure 2.1 [3]. Many studies were done on kenaf fibers as a reinforcement for plastics polymer with successful prove on their mechanical properties. This type of composites so called bio composites are composites that combine natural fibers like kenaf, jute and hump with either biodegradable or non-biodegradable polymer.

Figure 2.1: Various application of kenaf.

Ochi [8], on his study on a unidirectional long kenaf fibers reinforced poly-lactic acid (PLA) was stated that kenaf fibers have a great potential as a reinforcing fibers in thermoplastics composite because of its superior toughness and high aspect ratio. Rowell *et al.* [9] was compared the mechanical properties of kenaf reinforced polypropylene composites with other commonly used composites like glass fiber and E-glass. The results showed that kenaf fibers reinforced obtained a superior flexural modulus compare to glass fibers and the tensile modulus for both composites were comparable. Nevertheless, there are also some limitations in using the natural fibers as reinforcement. The low allowable processing temperature, incompatibility between hydrophobic polymer and hydrophilic natural fibers and high moisture absorption has restricted the potential of natural fibers as the reinforcement in thermoplastic composite [2]. Table 2.1 shows the property of kenaf fibers [10].

Table 2.1: Mechanical and physical properties of kenaf fibers [10].

Plant Fibers	Tensile strength (GPa)	Tensile modulus (GPa)	Elongation (%)	Density (g/cm³)	Moisture content (eq.) (%)	Aspect ratio, *L/D*
Kenaf	0.5	53	1.6	1.4	17	119

PET is one of the materials from thermoplastics polymer group. PET can be found in many different forms, from semi-rigid to rigid. It is a lightweight plastic that can be made into a number of different products. It is very strong and has high impact resistant properties as well. There are many different uses for PET. One of the most common is for drink bottles, including soft drinks and more.

The mechanical properties of PET which are very high strength, good chemical resistance, good work recovery and low moisture absorption has provide a good potential to PET to operate as a reinforcement. The mechanical and physical properties of PET fibers are listed in the Table 2.2 [11]:

Table 2.2: Mechanical and physical properties of PET fibers [11].

Fibers	Tensile strength (GPa)	Tensile modulus (GPa)	Elongation (%)	Density (g/cm³)	Water Uptake (%)	Melting Temp. (ºC)
PET	2.2	10	22	1.38	0.4	265

2.2 Polypropylene (PP)

PP is a linear hydrocarbon polymer. PP, like polyethylene (PE) and polybutene (PB), is a polyolefin or saturated polymer. PP is one of those most versatile polymers available with applications, both as a plastic and as a fiber. Figure 2.2 shows various application of PP in the market.

Figure 2.2: PP used in various application.

For physical properties, PP has offer excellent fatigue and chemical resistance at higher temperature. While the properties of PP are similar to those of PE, there are specific differences. These include a lower density, higher softening point and higher rigidity and hardness. Additives are applied to all commercially produce PP resins to protect the polymer during processing and to enhance end-use performance. The mechanical and physical properties of PP fibers are listed in the Table 2.3 [12].

Table 2.3: Mechanical and physical properties of PP [12].

Fibers	Tensile strength (MPa)	Specific modulus (GPa)	Elongation (%)	Melting Temp. (ºC)	Water Uptake (%)	Density (kg/m³)
PP	25-30	1.9	10	165	0.02	900

2.3 Hybrid Composites

In advanced, the study of hybrid composites has long taken attention of many researchers as a way to enhance the mechanical properties of composites. Hybrid composites are materials produce from the combination of more than two reinforcements in a matrix. Basically, they obtain a better property if compared with single reinforced composites [2]. Based on "rules of mixture" as shown in Eqn. 2.1 [13], the stiffness of composite is influenced by the elastic modulus of the reinforcement, matrix and their volume fractions. The equation is very beneficial in identifying the elasticity of the composite based on type and amount of reinforcement and matrix used before the real fabrication is proceed.

$$E_c = E_m V_m + E_{f1} E_{f1} + E_{f2} E_{f2} \qquad \textit{Eqn. 2.1}$$

where:

E_c = Elastic modulus of composite

E_m = Elastic modulus of matrix

E_f = Elastic modulus of fibers

V_m = Volume fraction of matrix

V_f = Volume fraction of fibers

Aji *et al.* [3] was investigated mechanical properties and water absorption behavior of hybridized kenaf/pineapple leaf (PALF) reinforced high density HDPL composite. He concluded that the clearest benefit of hybridized composites is that the reinforcement has potential to fulfill each other. On his study, PALF which has higher density of cellulose content compare to kenaf provide high tensile properties of the composites. Meanwhile, since kenaf has higher aspect ratio compared to PALF, it provided high flexural properties to the composite.

2.4 Fiber Composition

Besides, the mechanical properties of composites also dependent on the fiber content in the composites. In the study of composite material, Campbell *et al.* [1] stated that the fibers volume in continuous fibers composites must as high as 60 to 70 percent in order to obtain the highest strength and stiffness property. The statement has supported by Ochi [8] who discussed about the fibers content in his experiment on mechanical properties of kenaf fibers and kenaf/PLA composites.

He reported that the tensile and flexural strength of kenaf reinforced PLA composites, increase linearly with fiber contents up to 70%. Statically, in samples with a fiber volume fraction of 70%, the highest mechanical properties were obtained. The tensile and flexural strength of kenaf reinforced composites were approximately 223 MPa and 254 MPa, respectively. But, the tensile strength and flexural strength was expected to decrease after 70% fibers content as shown in Figure 2.3. The decreasing was due to insufficient filling of the matrix resin and the present of voids. Therefore, the fibers content used for fabricating kenaf composite reinforced should to be kept less than 70%.

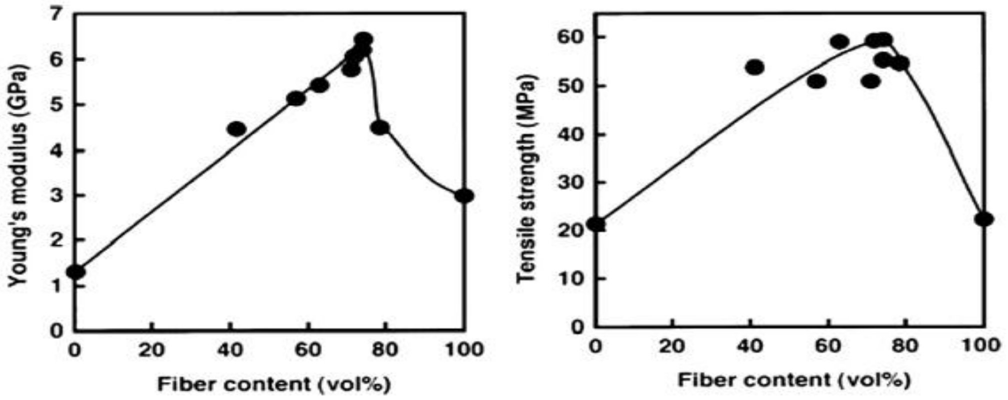


Figure 2.3: Relation between volume fraction and mechanical properties of composite.

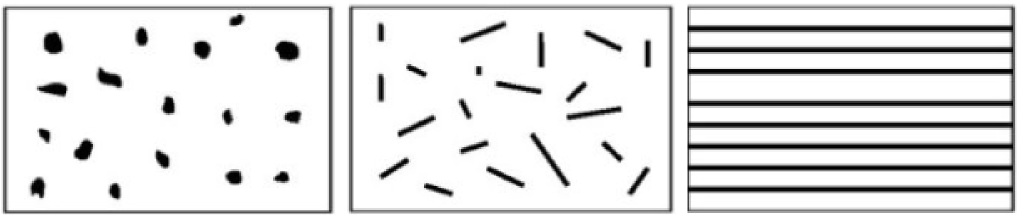
In hybrid composites, Aji *et al.* [3] found that when the fibers proportion of hybridized kenaf/pineapple leaf (PALF) reinforced high density HDPL composite was 50% by 50%, the composite obtained the highest tensile and flexural results. He stated that the ratio has offered optimal intermingling of the fibers and better adhesion of the matrix to fibers.

2.5 Processing Method

The processing methods of the hybrid composites also have to take into account. Recent study of processing methods has been done by comparing two manufacturing process which are compression moulding and injection moulding. When compared both of them, the most suitable process for long and continuous fibers composites is compression moulding. This is due to the preservation of isotropic properties of the composites as the orientation of the fibers is protected. In contrast, injection moulding will damage the properties of the fiber which result in changes in length and diameter distribution of the fiber which contribute to reduction of strength [15].

2.6 Reinforcement Types

Besides, the type of reinforcement of the hybrid composites also influenced the mechanical properties. According to Campbell *et al*. [1], the reinforcements present in two categories which are continuous and discontinuous reinforcement. Continuous reinforcement has higher aspect ratio (l/d). On the other hand, discontinuous reinforcement has lower aspect ratio. Figure 2.4 shows the schematics diagram of various type of reinforcement.



(a) (b) (c)

Figure 2.4: Schematics diagram of various type of reinforcement. (a) particulate, (b) short fibers and (c) unidirectional continuous fiber [13].

According to Smith *et al.* [15], the physical and mechanical behaviour of particulate system is uniform in all direction. In short fiber system, the behaviour is usually planar isotropic where the properties are uniform in planar direction. On the other hand, the long fiber system is anisotropy where the properties are dependent on the direction of the fiber. Among the two systems, the one which reinforced with long fiber exhibits the best mechanical properties when the load applied is parallel with the fiber direction.

2.7 Commingled Process

Commingled is one of the method used in hybrid composite where the fiber is twisted together to become like one strand of reinforcement. George *et al.* [16] were prepared jute yarn reinforced polypropylene composites by commingling method. On the experiment, he used a specific layer pattern by using winding machine specifically design for commingling. From the discussion, he stated that commingling process is one of the best methods of intermingling the fiber and matrix with good alignment.

In the other study, Golazar *et al*. [7] were determined that one of solution to obtain good impregnation in hybrid composite is by having a close contact between the reinforcement and matrix. So, he suggested that commingled structure of hybrid fiber as shows in Figure 2.5 as the solution. He concluded that commingled structure will offer a better composites properties compare to side by side fiber because of the close contact between the fiber and the matrix.

(a) (b)

Figure 2.5: Diagram of (a) commingled fibers and (b) non-commingled fiber.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Project Activities

3.1.1 Chemical treatment of kenaf fibers

Sodium Hydroxide (NaOH) solutions with concentration of 6% by mass were used for the alkali treatment. Kenaf fibers were immersed in the NaOH solution for 24 h at room temperature. After immersion, the fibers were washed with running distilled water for 7 times. These fibers were then dried in an oven at 50°C for a period of 8 h.

3.1.2 Commingled process

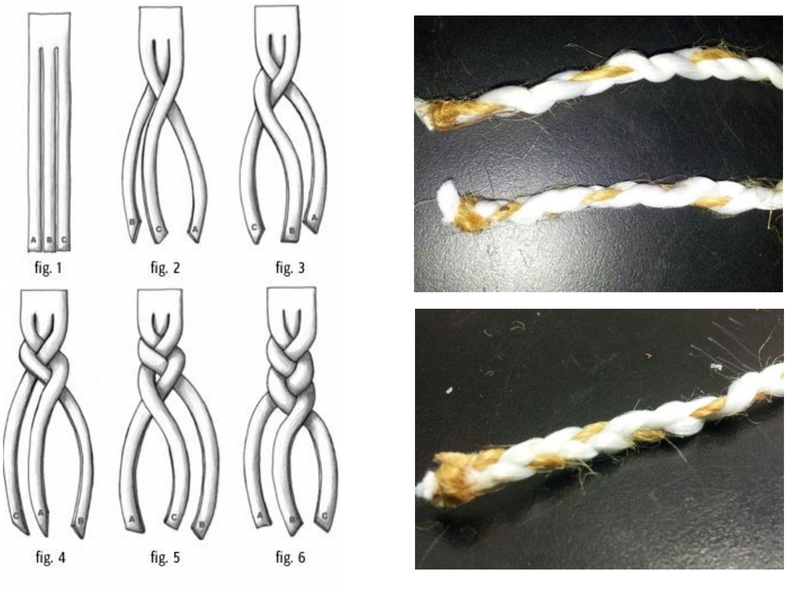
In this research, two types of fiber orientation in hybrid polymer composites were studied by using a commingled yarn structure which are twisted together and non-commingled yarn structure which are free of twist. The kenaf and PET fiber arrived at our lab in roving form as shown in Figure 3.1.

Figure 3.1: Kenaf fiber and PET fiber in roving form.

Figure 3.2 shows both fibers were cut to approximately 165 mm in length prior to the commingling process.

Figure 3.2: PET and Kenaf Fiber in 165 mm of length.

Based on 15% of fiber weight fraction, for composition 85/5/10, 0.5 g of kenaf fiber and 1.0 g of PET fiber were prepared meanwhile, for composition of 85/10/5, 1 g of kenaf fiber and 0.5 g of PET fibers were prepared. Manual braiding method is using for commingling kenaf and PET fiber. The process and the end product of commingling are shown in Figure 3.3.



(a) (b)

Figure 3.3: (a) Steps of manual braiding method and
(b) Kenaf/PET fiber after commingled.

3.1.3 Fabrication of Composites Specimens.

The compression moulding technique was used to fabricate kenaf/PET reinforced PP composites. The PP was in the layer form while both kenaf and PET fibers were in long fiber form. The manufacturing process comprised five stages, namely; mold loading, pre heating, heating under compression, cooling under compression and mold unloading. The first step was to load the mold cavity with the particular composite. Sandwich technique was used during the process by sandwiching both kenaf and PET fiber with layer of PP. Prior to the process, layer of PP was made using a similar compression moulding technique with different processing parameter. The quantity of PP granule was calculated to achieve the desired fiber content for each composite. The summary of procedure of preparing PP layer is shown below.

A thin layer of wax was applied to the mold cavity in order to ensure the composite was easily to remove out. The closed mould was then loaded into the compression moulding and exposed to the heat for a period of 15 minutes with temperature is set to 220°C. The compression of the moulding was started after 15 minutes of preheating where the mold subjected a compressive load 30 minutes. The temperature was maintained to lower the viscosity of the matrix system allowing the PP to penetrate kenaf and PET fiber. Then, the closed mold was allowed to cool down under compressive load until the temperature reach 80°C - 90°C. Finally, the fabricated composite was released from the mould. Figure 3.4 shows full sequences of procedure in pictures.

<u>Process of making PP layer</u>

1. The PP pallet was weighed about 8 g by using electronic weighing machine.
2. Then, the PP pallet was put into the mould cavity.
3. The compression machine was setup at 180°C and 10 ton force.
4. The mould was then loads to the compression moulding machine and allow for preheating for 10 minutes.
5. Then, the mould was compressed and heated by the machine for 15 minutes.
6. After that, the mould is allowed to cool down until 80°C - 90°C.
7. Finally, the layer of PP was removed out from the mould cavity.

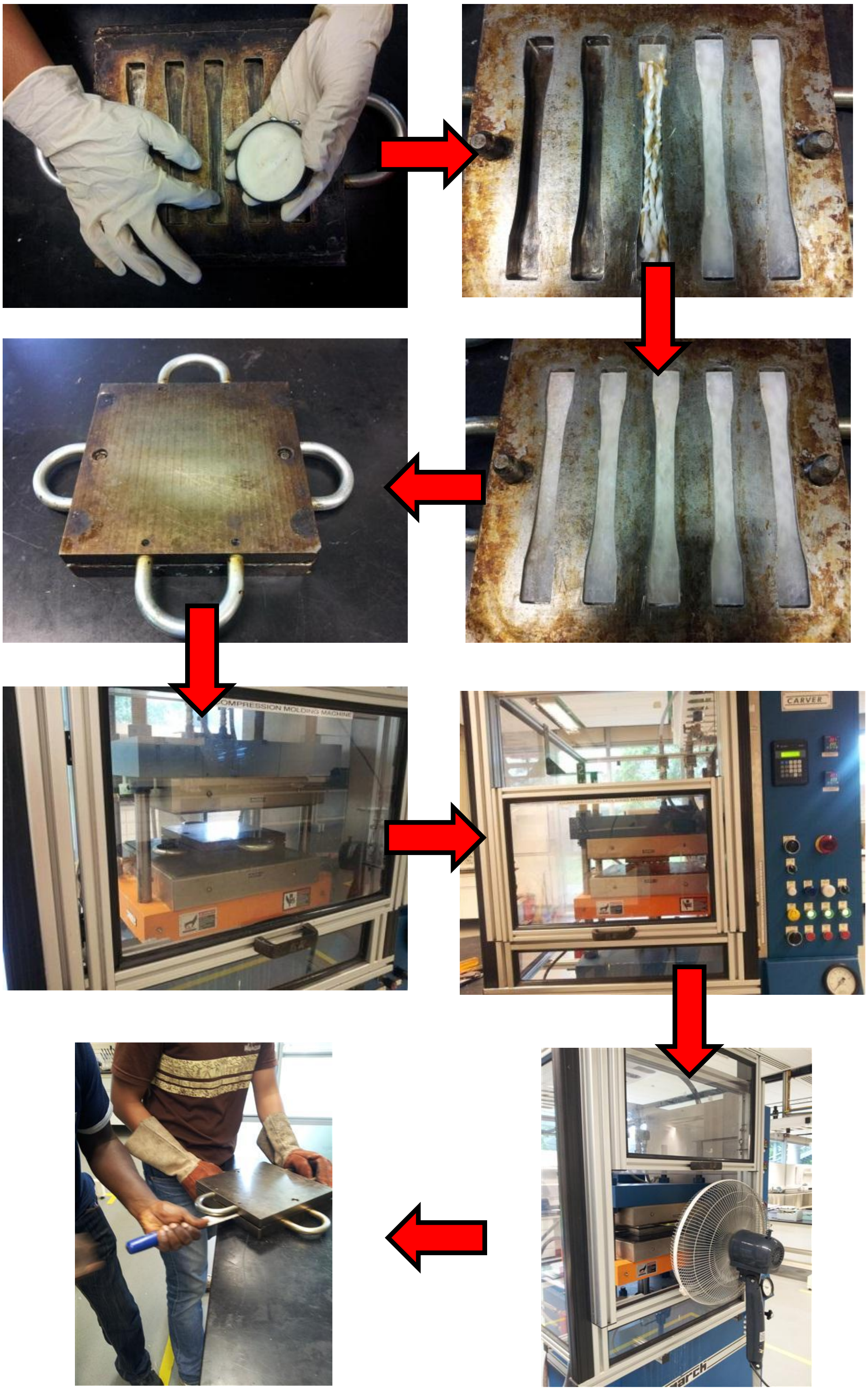


Figure 3.4: Steps of procedure on composite processing.

3.1.4 Composites Composition

Two different configurations of kenaf/PET reinforced PP composites were produced. There were commingled kenaf/PET reinforced PP and non-commingled kenaf/PET reinforced PET. Two different composite mass fractions; 85/5/10 and 85/10/5 were considered. Five samples were produced for each composition and configuration. Each fabricates composite was in dog bone shape with the dimension was accordance to ASTM D638 for tensile specimens while ASTM D790 for flexural. Table 3.1 shows the composition for each sample.

Table 3.1: Weight fraction.

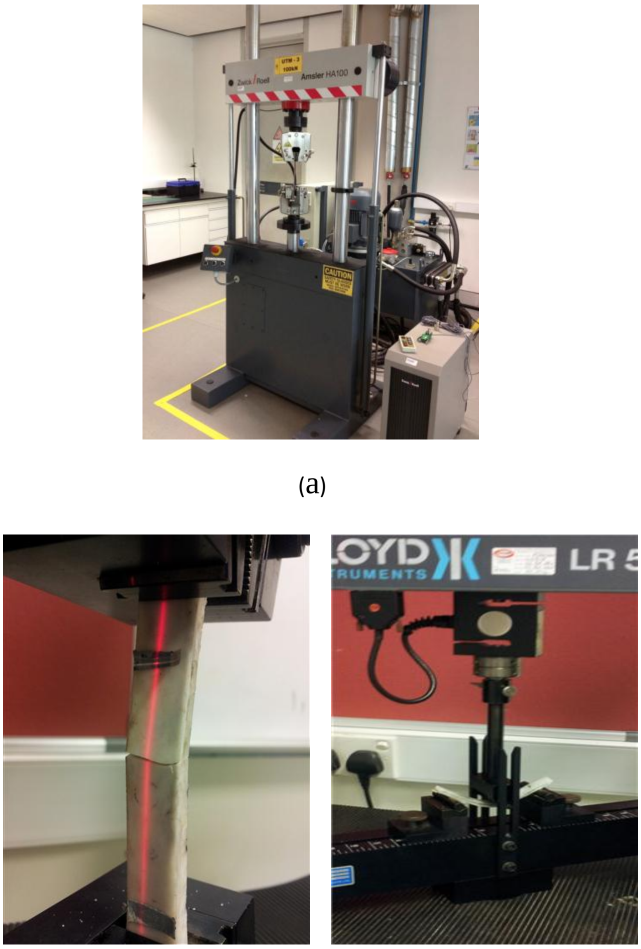
Sample	Fibers Type	Weight fraction PP	Weight fraction of Kenaf Fibers	Weight fraction of PET Fibers
1	Commingled	0.85	0.05	0.10
2	Commingled	0.85	0.10	0.05
3	Non-Commingled	0.85	0.05	0.10
4	Non-Commingled	0.85	0.10	0.05

3.1.5 Tensile Test

In order to obtain the tensile properties of the samples, the tensile test was conducted on at least 5 samples in room temperatures of 25ºC by using a Universal Testing Machine LLOYD as Figure 3.5 (a). In this test, the specimens would be gripped at both ends and followed an exertion of tension until the specimen fails as shown in Figure 3.5 (b). After the test, several parameters would be direct and indirectly obtained which are the ultimate tensile strength, elastic modulus, poisson’s ratio, yield strength, maximum elongation, and reduction in area. The loading speed set was 2 mm/min. To tighten the gripper and prevent slipping from happening during the testing, both end of the specimens was scratch out prior to the testing.

3.1.6 Flexural Test

For obtaining the flexural properties of the composites, 3-points bending test would be conducted accordingly based on ASTM standard D790. At least five specimens were tested in the room temperature of 25°C by using Universal Testing Machine LLYOD as shown in Figure 3.5 (c). After the test, the parameters that would be obtained are flexural strength, strain and modulus. The specimen was placed onto two supports having a 40 mm span length between the supports. The crosshead speed was set to 10 mm/min.



(a)

(b) (c)

Figure 3.5: Diagram of (a) universal testing machine, (b) tensile test and (c) flexural test.

3.2 Gantt Chart and Key Milestones

Several targets have been set for the FYP I and FYP II. Figure 3.6 shows the overall activities throughout the two semesters while in Table 3.2 shows the project activities and key milestones for FYP I and FYP II respectively

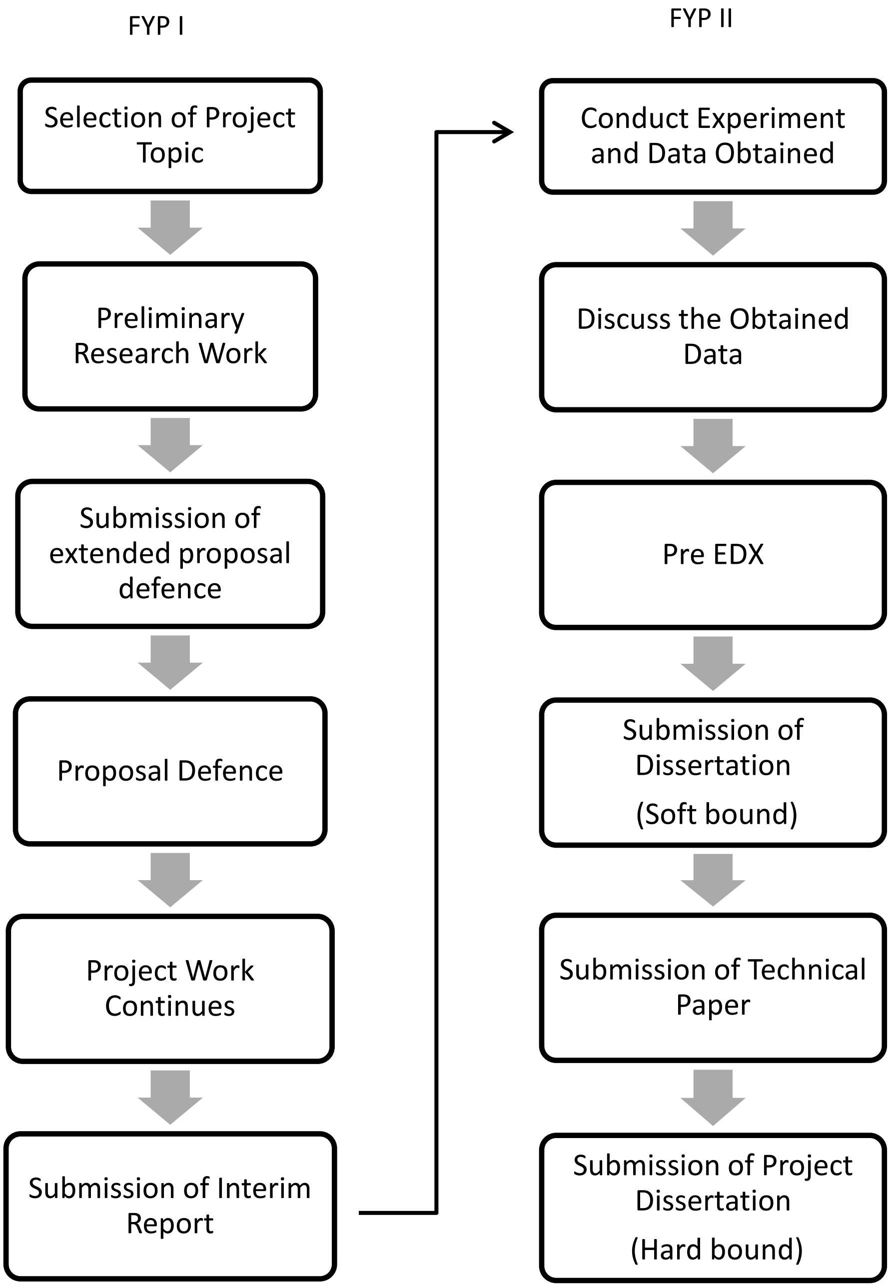


Figure 3.6: Overall activities throughout two semesters.

Table 3.2: Project activities and key milestones for FYP I and FYP II.

ID	Task Name
0	**FYP 1 & 2**
1	**FYP 1**
2	**Selection of Project Topic**
3	Approach lecturers for potential topics
4	Screen the potential topics
5	Confirming the topic and supervisor
6	**Preliminary Research Work**
7	Define the problem statement
8	Background study of the project
9	Literature Review
10	Prepare the Methodology
11	Equipment and facilities survey
12	**Submission of extended proposal defence**
13	Prepare draft proposal
14	Final Submission
15	**Proposal Defence**
16	Prepare slide presentation
17	Proposal Defence Presentation
18	**Project Work Continuation**
19	Familiarize with material and machine used
20	Fabrication of sample
21	**Submission of Interim Report**
22	Prepare the interim draft report
23	Consultation with supervisors
24	Finalize the interim report
25	Final Submission
26	**FYP 2**
27	**Project Work Continuation I**
28	Conduct Experiment and Data Obtained
29	Submission of Progress Report
30	**Project Work Continuation II**
31	Discuss the Obtained Data
32	Pre EDX
33	Submission of Draft Report
34	Submission of Dissertation (Soft bound)
35	Submission of Technical Paper
36	Oral Presentation
37	Submission of Project Dissertation (Hard bound)

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Theoretical Result

The “rules of mixture” was used to calculate the tensile strength and tensile modulus of the composite. Table 4.1 shows the “rules of mixture” equation of hybrid composite materials.

Table 4.1: Equation of “Rules of mixture”.

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

Table 4.2 shows the parameter of the calculation. The design parameter for the calculation is basically acquired from the mechanical properties of the fiber and matrix itself.

Table 4.2: Parameter for calculation.

Fibers/Pallet	Density, ρ (g/cm^3)	Tensile strength, σ_c (MPa)	Tensile modulus, E_c (GPa)
Kenaf	1.5	450	40
PET	1.4	2200	10
PP	0.9	33	1.3

Based on the formula and given parameters, the calculation of tensile strength and tensile modulus of the composite were done as below:

Tensile Strength, σ_c

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

$$\sigma_c = (0.45)(0.1) + (2.2)(0.05) + (0.033)(0.85)$$

$$\sigma_c = 183.1 \text{ MPa}$$

Elastic Modulus, E_c

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

$$E_c = (40)(0.1) + (10)(0.05) + (1.3)(0.85)$$

$$E_c = 5605 \text{ MPa}$$

Graphical representations, shown in Figures 4.1 and 4.2, can be generated to view the results of the analytical calculations. As expected, the tensile strength of non-commingled 85/5/10 hybrid composite was higher compared to 85/10/5 due to higher tensile strength offered by PET. Meanwhile, for tensile modulus, non-commingled 85/10/5 hybrid composite obtained better result compared to 85/5/10 due to higher tensile modulus provided by kenaf.

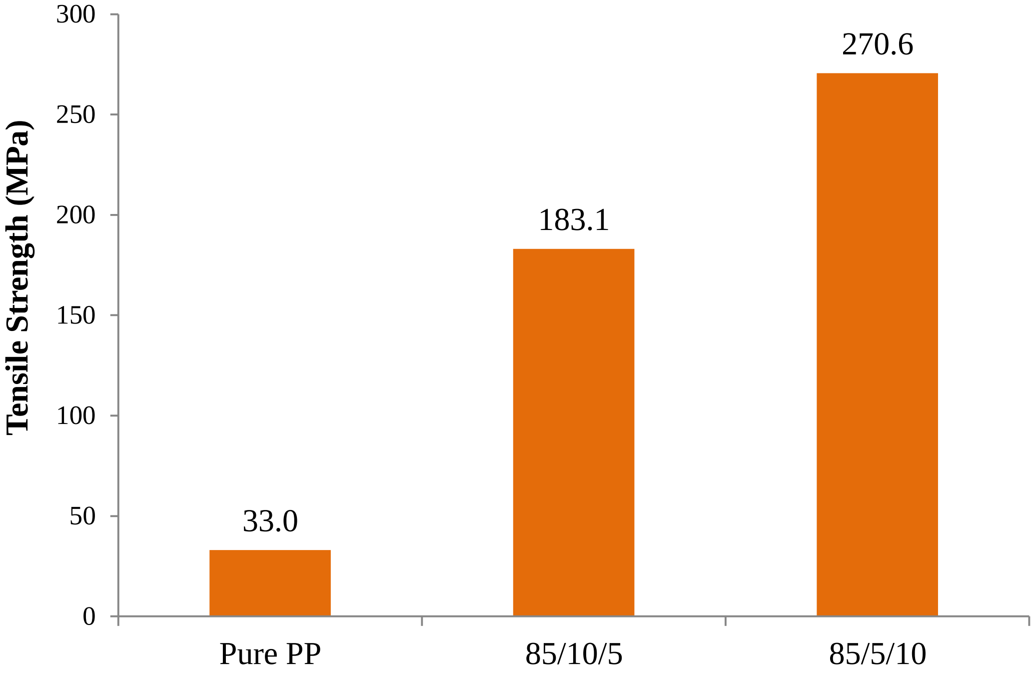


Figure 4.1: Graph of analytical tensile strength of hybrid composite.

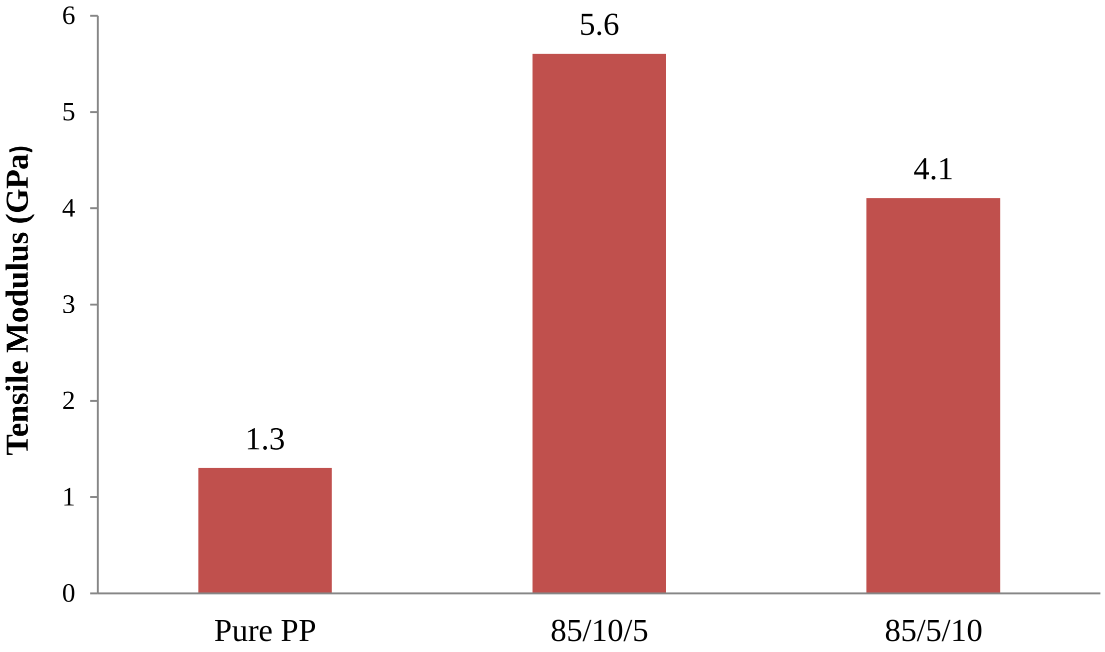


Figure 4.2: Graph of analytical tensile modulus of hybrid composite.

4.2 Data Analysis

4.2.1 Tensile Properties

The data obtained from tensile test was tabulated in Table A-1 (Appendix). The results for tensile strengths were graphically summarized in Figure 4.3. Tensile strength of non-commingled 85/10/5 and 85/5/10 improved by approximately 18% and 32%, respectively, compared to neat PP. The highest improvement was observed in commingled 85/5/10 with increment of 48%. The commingled process contributed to tensile strength improvements of approximately 15% and 16% for non-commingled 85/10/5 and 85/5/10, respectively.

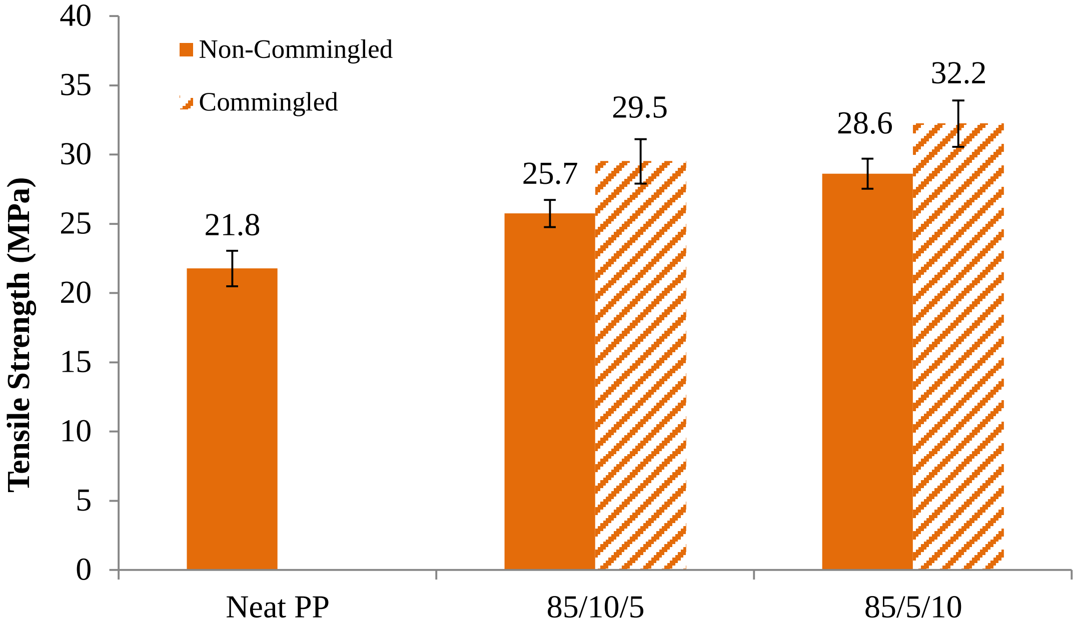


Figure 4.3: Graph of tensile strength of hybrid composite.

Morphological characteristics of the samples were studied using Field Emission Scanning Electron Microscope (FESEM) as shown in Figures 4.4 and 4.5. Non-commingled 85/5/10 specimen in Figure 4.4 shows the presence of void while commingled 85/5/10 specimen in Figure 4.5 shows no void. Therefore, it was proven that commingled process provides a good interfacial bonding between reinforcement and matrix.

Figure 4.4: FESEM images of fracture surface of non-commingled 85/5/10 hybrid composite.

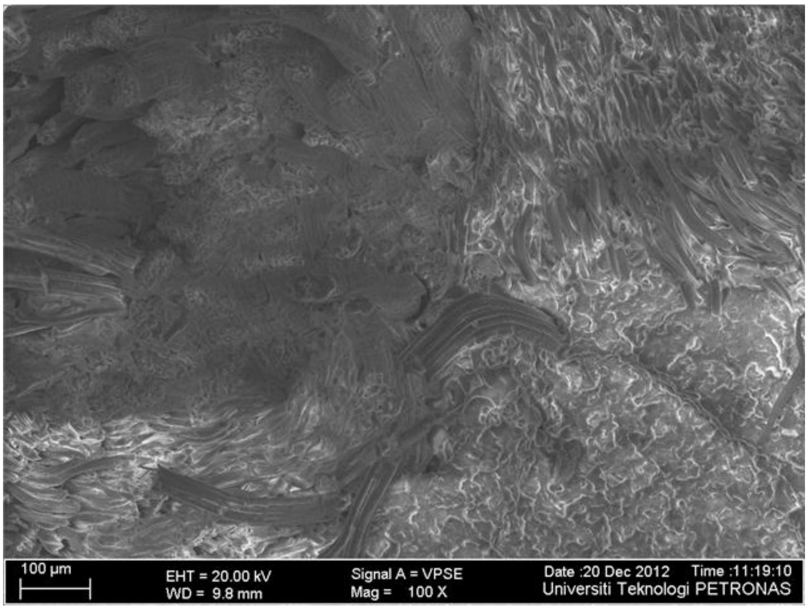


Figure 4.5: FESEM images of fracture surface of commingled 85/5/10 hybrid composite**.**

While comparing the sample in term of fiber weight percentage, it showed that the composite with 10 wt.% of PET have obtained a better tensile strength. Tensile strengths of non-commingled 85/5/10 and commingled 85/5/10 showed improvements of approximately 11% and 9% compared to non-commingled 85/10/5 and commingled 85/10/5, respectively. This is because of PET fiber has higher tensile strength compare to kenaf fiber.

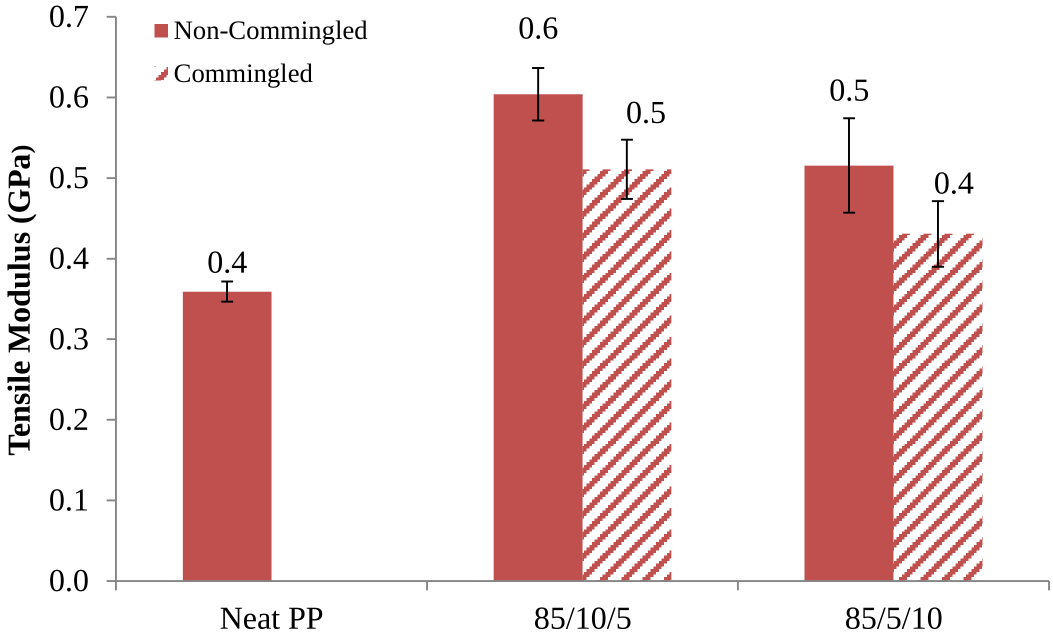


Figure 4.6: Graph of tensile moduli of hybrid composite.

The results for tensile moduli were graphically summarized in Figure 4.6. Tensile moduli of non-commingled 85/10/5 and 85/5/10 improved by approximately 68% and 42% compared to neat PP, respectively. The highest improvement was observed in non-commingled 85/5/10 with increment of 68%. The commingled composite was not significantly contributed to tensile modulus improvements. Tensile moduli of commingled 85/10/5 and 85/5/10 improved by approximately 43% and 20% compared to neat PP, respectively. This situation could be explained by lower fiber distribution of the commingled fiber and lower fiber spreading in the commingled composite as shown in Figure 4.7.

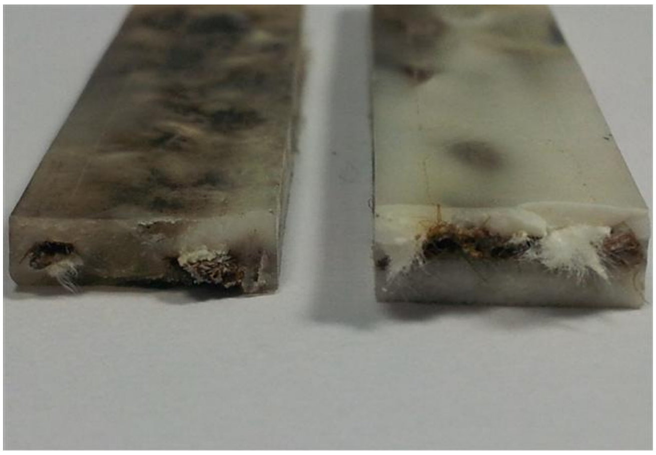


Figure 4.7: Picture of cross section area of specimen after flexural testing.

While comparing the sample in term of fiber weight percentage, it showed that the composite with 10 wt.% of kenaf obtained a better tensile modulus. Tensile moduli of non-commingled 85/5/10 and commingled 85/5/10 showed improvements of approximately 18% and 19% compared to non-commingled 85/10/5 and commingled 85/10/5, respectively. One explanation to this is that kenaf fiber has higher tensile modulus compared to PET fiber. Therefore, the higher the weight fraction of kenaf in the hybrid composite, the higher the tensile strength obtained by the composite.

The experimental results showed the similar performance of tensile properties when compared to the analytical calculation. However, the analytical results showed much higher data compared to the experimental results due to the assumptions of perfect interfacial bonding with no void inside the hybrid composite.

4.2.2 Flexural Properties

The data obtained from flexural test was tabulated in Table A-2 (Appendix).The results for flexural strengths were graphically summarized in Figures 4.8. Flexural strengths of non-commingled 85/10/5 and 85/5/10 improved by approximately 38% and 20% compared to neat PP, respectively. The highest improvement was observed in non-commingled 85/10/5 with increment of 38%. The commingled composite was not significantly contributed to flexural strength improvements. Flexural strengths of commingled 85/10/5 and 85/5/10 improved by approximately 15% and 30% compared to neat PP, respectively.

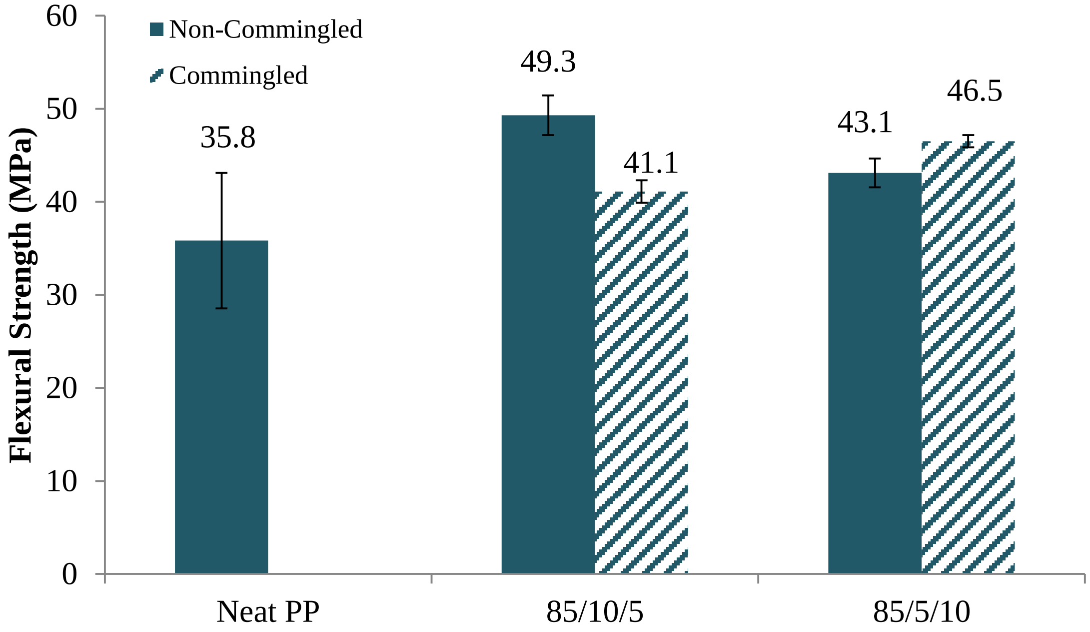


Figure 4.8: Graph of flexural strength of hybrid composite.

The results for flexural moduli were graphically summarized in Figures 4.9. Flexural moduli of non-commingled 85/10/5 and 85/5/10 improved by approximately 71% and 87% compared to neat PP, respectively. The highest improvement was observed in non-commingled 85/5/10 with increment of 87%. The commingled composite was not significantly contributed to flexural modulus improvements compared to non-commingled composite. Flexural moduli of commingled 85/10/5 and 85/5/10 improved by approximately 42% and 53% compared to neat PP, respectively. This situation could be explained by lower fiber distribution of the commingled fiber and lower fiber spreading in the commingled composite.

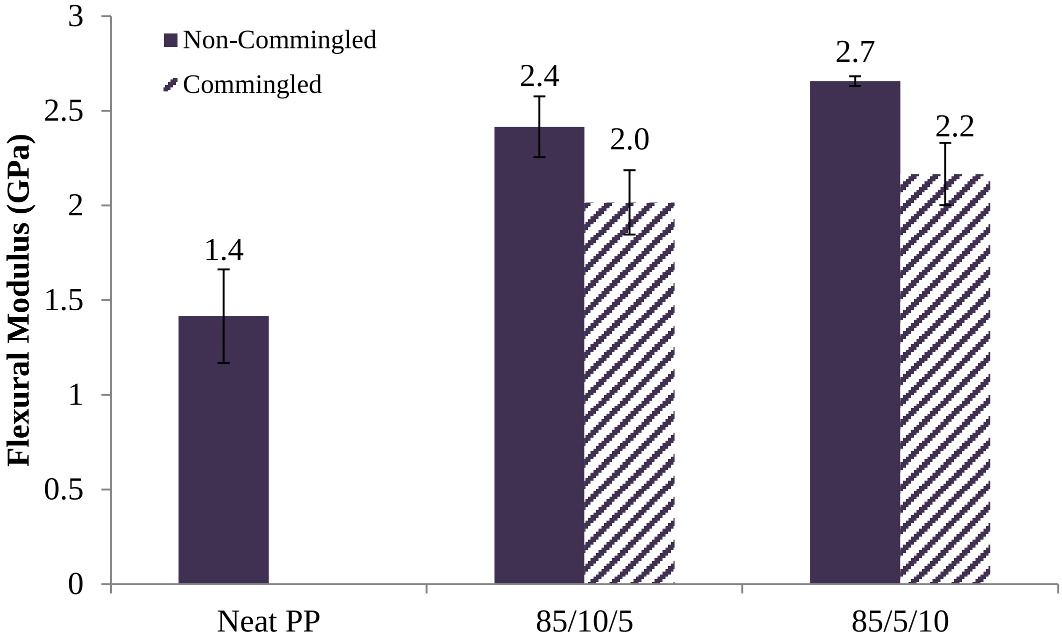


Figure 4.9: Graph of flexural moduli of hybrid composite.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The objective of this project was achieved. Mechanical test results and FESEM examination showed that commingled process significantly improved the tensile strengths of the composites. The results can be summarized as follows:

- Commingled hybrid composite of 85/5/10 obtained the highest tensile strength with the increment of 48% compared to neat PP due to high percentage of PET fiber that provided high tensile strength, and good interfacial bonding between the fibers and the matrix provide by the commingled process.
- Non-commingled hybrid composite showed better flexural properties compared to the commingled hybrid composite. The highest improvement of the flexural strengths and flexural moduli were obtained by non-commingled composites with increment of 38% and 87% compared to neat PP, respectively.

5.2 Recommendation

As for the future work, it is recommended to determine the mechanical properties of the commingled kenaf/PET reinforced PP hybrid composites with variation of volume fraction in order to get the optimum volume fraction. Apart from that, other mechanical and physical tests should be done in order to observe the true potential of commingled kenaf/PET fibers as the reinforcements.

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APPENDIX A

Table A-1: Tabulated data of tensile properties.

Sample	Tensile Strength (MPa)			
	85/10/5	85/5/10	Commingled 85/10/5	Commingled 85/5/10
1	28.30	24.31	31.79	30.00
2	27.59	25.95	28.48	32.61
3	29.96	26.96	28.27	34.07
Avg	28.61	25.74	29.51	32.23
Std	0.99	1.09	1.61	1.68

Sample	Tensile Modulus (GPa)			
	85/10/5	85/5/10	Commingled 85/10/5	Commingled 85/5/10
1	604.1	492.3	508.7	464.4
2	571.5	553.0	461.0	442.1
3	636.6	486.7	577.2	385.6
Avg	604.1	510.7	515.6	430.7
Std	32.56	36.77	58.43	40.60

Table A-2: Tabulated data of flexural properties.

Sample	Flexural Strength (MPa)			
	85/10/5	85/5/10	Commingled 85/10/5	Commingled 85/5/10
1	49.65	44.90	42.49	47.10
2	47.03	42.40	40.26	45.80
3	51.21	42.06	40.54	46.59
Avg	49.30	43.12	41.10	46.50
Std	2.12	1.55	1.21	0.65

Sample	Flexural Modulus (GPa)			
	85/10/5	85/5/10	Commingled 85/10/5	Commingled 85/5/10
1	2251.46	2682.48	1888.26	1999.25
2	2423.83	2631.75	2208.35	2170.05
3	2571.75	2657.58	1949.55	2328.19
Avg	2415.68	2657.27	2015.39	2165.83
Std	160.30	25.37	169.89	164.51