TENSILE AND FLEXURAL PROPERTIES OF RECYCLED PP/KENAF/PET HYBRID COMPOSITES

By

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

SEPTEMBER 2012

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
In partial fulfillment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL ENGINEERING)

Approved by,

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UNIVERSITI TEKNOLOGI PETRONAS
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 persons.

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ABSTRACT

Composite materials have been preferred by many applications due to their unique properties such as resistant to corrosion, lightweight and relatively inexpensive. However, these materials contribute to approximately 10% of municipal solid waste in the United States. Therefore, this project was proposed to study the tensile and flexural properties of recycled PP/kenaf/PET with and without coupling agent. The raw materials for this project were obtained from used specimens of PP/kenaf/PET commingled hybrid composites. The specimens were shredded according to their original compositions using granulator. Due to limitation of mould cavity used in the compression moulding, only two compositions i.e. 85/10/5 and 85/5/10 (PP/kenaf/PET) wt. % were produced. The results showed reduction of approximately 30% for tensile strength, tensile modulus, and flexural strength of the recycled hybrid composite while flexural modulus recorded approximately 10% increment compared to the virgin hybrid composite. Coupling agent inflicted an adverse to the tensile and flexural properties of the recycled hybrid composite.

ACKNOWLEDGEMENT

The author would like to express his gratitude and appreciation to Universiti Teknologi PETRONAS for the laboratory facilities. Besides, the author also wishes to give his utmost appreciation to his supervisor, Dr Mohamad Zaki Bin Abdullah for his guidance, attention, and helping throughout the final year project progress and his continuous support since beginning until the end of period. Lastly, the author also wants to thank the lab technologists, technicians, and staff of UTP as well as fellow friends who help the author in completing the final year project.

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CHAPTER 1

INTRODUCTION

1.1 Background of study

Composite has gained interest of automotive, household and other industries due to its unique properties such as resistant to corrosion, lightweight and relatively inexpensive. In 1995, approximately 10% of municipal waste from residential, commercial and institutional units in the United States is composite [1]. As the world population increases, the composite waste will also increase. One potential way to tackle growing amount of composite waste is by recycling the waste. By definition, recycling is the process of making or manufacturing new products from a product that originally served its purpose.

With the growing environmental consciousness [2], several industries such as automotive, construction, sports and leisure, and housing appliance have initiated the move towards sustainable and renewable reinforced composites by implementing the usage of natural fiber composite in their products. The attractive mechanical property of natural fiber as well as relatively low cost has gained much attention [3].

Another important constituent that made up a composite is known as matrix or binder. Usually, thermoset is more preferred due to its strength and high-temperature application. But it is not recyclable [4]. On the other hand, thermoplastic can be recycled even though most of thermoplastics have lower strength compared to thermoset. Perhaps, thermoplastic matrix together with natural fiber reinforcement is the choice for the future to save environment. Potential application for recycled thermoplastic/natural fiber composite is plastic lumber (e.g. deck floor and fence).

The mechanical properties of recycled composite may be reduced compared to virgin composite mainly because it has been degraded throughout its lifespan. The use of coupling agent could enhance the interfacial bonding between the matrix and reinforcement [5].

1.2 Problem statement

Thermoplastic natural fiber reinforced composite has recyclable property because both materials can be recycled. However, very limited studies have been done on mechanical properties of recycled hybrid composite. In addition, attempts to study the effect of coupling agent on mechanical properties of recycled hybrid composites are rare. The result of this study can be used to identify the potential application of the recycled hybrid composite. This work is expected to reduce the environmental problem by recycling the composite waste into a useful application.

1.3 Objective

The objective of this project is to study the tensile and flexural properties of recycled PP/kenaf/PET hybrid composites with and without coupling agent.

1.4 Scope of study

The raw materials for this project were obtained from used specimens of commingled kenaf and PET fibers reinforced PP hybrid composites with 85/5/10 and 85/10/5 (PP/kenaf/PET) wt.%. Samples were prepared using compression moulding technique. Coupling agent used was maleic anhydride modified PP (MAPP).

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Until the 1990s, almost 90% of commercial polymeric materials filled up landfills whilst 10% was incinerated. In 1991, 74 billion tons of plastic materials were discarded in the United States with less than 2% was recycled. Due to the increasing awareness of environmental impact, European law mandated almost total recycling of most materials, including thermoplastic polymers [6]. Thermoplastic in natural fiber composites are potentially recyclable and can be considered sustainable materials, as the natural fiber composite can be obtained from post industrial waste [7].

For composite recycling, a difficulty arises in sorting. It is almost difficult to differentiate the composition of matrix and fiber of a product. The segregation of composite is very important so that the same material will be gathered and processed together. A standard identification codes for composites can be established to solve the issue.

2.2 Recycled hybrid composite

The recycling process normally will result in particulate composite which is the same category of short fiber. To get better performance of short fiber for the recycled composite, the process parameter and manufacturing technique must be considered carefully. Valente *et al.* [7] reported that the recycled glass fibers provided strength values which were comparable to those of the virgin ones, highlighting that recycling operation did not affect the reinforcing efficiency of the fibers even though a suitable coupling agent was needed between glass and polymer.

Brachet *et al*. [5] had carried out a study on the mechanical properties obtained with the blending of a stabilized recycled PP from post-consumer waste with different compositions of coupling agent which were ethylene-octane rubber (EOR) and calcium carbonate. The elastomer EOR was added to enhance toughness and impact properties while calcium carbonate was used to improve hardness and stiffness to the specimens. He reported that as the concentration of calcium carbonate and elastomer increased, the yield stress decreased with minor effect. He summarized that no enhancement of properties recorded. He suggested that a high quality elastomer used with optimized processing parameter could have enhanced the property of recycled material.

A number of researchers investigated the influence of the addition of a coupling agent on the mechanical properties of compound. For PP based composite, maleic anhydride modified PP was found to be effective in increasing the strength of injection moulded composites [8-10].

Natural fiber is often compared with synthetic fiber such as glass and carbon. Sometimes, the natural fiber is nominated as an alternative to replace synthetic fiber. The availability and cost reduction, which is a *defacto* feature of the natural fiber, make it utterly a favorable choice of material for industrial player. The use of natural composites in various applications has acquired much interest as it is a leap step towards making the world greener and eco-friendly.

The processing parameters like fiber area fraction, moulding temperature and forming pressure have great influence on the mechanical property of composites. The challenges posed by natural fiber polymer composites are interfacial bonding and water absorption [3]. The interfacial issue is about the incompatibility between hydrophilic fibers and hydrophobic thermoplastic matrices, while natural fiber inherits high percentage of water absorption [3, 11].

Sarasini *et al.* [7] suggested a possible solution to improve the mechanical properties of natural fiber reinforced composites was by the hybridization with inorganic fillers. Hybridization may cover the disadvantages of one component with the addition of another component. Sarasini *et al.* [7] had studied manufacturing and mechanical characterization of recycled hybrid glass fiber/wood flour thermoplastic composites. They concluded that the addition of glass fiber as second reinforcement had enhanced the mechanical property of the composite.

Shakeri *et al*. [12] carried out a study on mechanical performance and water absorption of recycled newspaper/glass fiber reinforced PP hybrid composites. The results showed improvements in the mechanical properties of the composite.

2.3 Processing method

Compression moulding and injection moulding processing are the common methods used to produce natural fiber reinforced composites. Mohanty *et al.* [13] reported that injection moulding improved the fiber dispersion and subsequently increased tensile and flexural properties. Liu *et al.* [14] studied the importance of processing conditions and mould used. He concluded that more pressure was transferred to the composite in closed mould rather than in a frame mould. Ochi [15] reported that the most suitable processing conditions of kenaf fiber were at 160°C for 60 minutes or 180°C for 30 minutes to avoid thermal degradation.

Liu *et al.* [14] suggested that impact strength of compression moulded bio-composites was higher than that of the injection moulded samples. Another important factor that significantly influences the properties and interfacial characteristics of the composite is the processing parameters [16]. In addition, it is of important to know the length of fibers used to identify the best possible moulding method. Table 2-1 shows the recommended processing methods corresponding to the fiber lengths.

Table 2-1: Common method used for short fiber [17].

Type	Moulding method	Fiber lengths (cm)	Fiber orientation
Fiber-reinforced thermoplastics	Injection moulding	$<$ 1.25	Random or dependent on flow in mould
Sheet-moulding compound (polyester resin matrix)	Compression moulding or sheet stamping	2.5-7.5	Random in compound but dependent on flow in mould
Bulk-moulding compound	Compression moulding	$<$ 2.5	

2.4 Rule of mixture

In hybridization, the properties to be obtained largely depend 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. Limitation of hybrid strength is depending on the failure strain of individual fibers. That is why maximum hybrid strength is obtained when the strain of combining fibers are closely compatible. The properties of hybrid composites of two components can also be predicted by the rule of mixtures, where P_h is the property to be investigated, P_1 corresponding property of the first system and P_2 corresponding to property of the second system. V_1 and V_2 are the relative hybrid volume fractions of the first and second systems, respectively.

$$\boldsymbol{P_h = P_1V_1 + P_2V_2} \text{ ....Equation 1}$$

$$\boldsymbol{E_c = V_mE_m + V_{f1}E_{f1} + V_{f2}E_{f2}} \text{......... Equation 2}$$

where:

E_c = Elastic modulus of composite

E_m= Elastic modulus of matrix

E_f = Elastic Modulus of fiber

By definition, hybrid composite is a material comprises of two reinforcements and matrix. In composite, fiber acts as the reinforcement to support the structure. As shown in Eqn. 2, the fiber and matrix (binder) are the components that contribute to the stiffness of composite.

2.5 Material composition

Aji *et al.* [18] studied the mechanical properties and water absorption behavior of kenaf/pineapple leaf fiber (PALF) reinforced HDPE composites. The composites were prepared at various compositions with a constant fiber length of 25 mm. He reported that at 60/24/16 (HDPE/kenaf/PALF), fiber was able to effectively share the load with PALF which transferred the load from the matrix to the fiber. Better dispersion of matrix in the composite was achieved, enhancing synergistic relationship among fibers and matrix. At 60/20/20, positive hybridization effect was optimized. This was possible because the elongations at break of the two fibers were about the same, which induced their ability to provide enhanced performance in tension. They also reported that at 60/28/12 or 60/12/28, tensile properties were the lowest because the reinforcements did not provide adequate synergistic loading to encourage transfer of stress among the fibers.

In composite, loads are not directly applied on the fibers but are applied to the matrix material and transferred to the fibers through the fiber ends. When the length of a fiber is much greater than the length in which the transfer of stress takes place, the end effects can be neglected and the fiber may considered continuous. In the case of short fiber composite, the end affects cannot be neglected and the composite properties are a function of fiber length.

Moisture absorption can affect the flexural properties of composites. Study made by Osman *et al.* [19] on kenaf/recycled jute natural fibers unsaturated polyester composites showed that the flexural properties of kenaf fiber composites decreased drastically on exposure to water immersion. This was due to the formation of hydrogen bonding between the water molecules and cellulose fiber.

2.6 Mechanical and physical properties of materials used

The mechanical and physical properties of materials used in this project are shown in Table 2-2. The melting temperature of the matrix is intended to be lower than reinforcement fiber. The temperature gap between them should be large enough to prevent any possibility for the reinforcement to melt.

Table 2-2: The properties of materials used.

Properties/ Material	LDPE [18]	PP [18]	Kenaf [19]	PET [18]	MAPP
Tensile strength, σ (MPa)	12	30	295 - 1191	55	-
Tensile modulus, E (GPa)	0.3	1.3	22 - 60	2.7	-
Flexural strength, (MPa)	25	29	-	80	-
Flexural Modulus, (GPa)	0.35	0.5	-	1	-
Melting Temperature, (°C)	136	165	-	250	162
Water absorption, (%)	0.015	0.01	17	0.2	-
Density, ρ (kg/m^3)	928	907	1220-1400	1400	903

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Project activities

In order to produce recycled hybrid composites samples, numbers of virgin samples were made beforehand. The samples were put under series of mechanical testing and plastic shredded. The samples coming out from granulator was short fiber composites. Two compositions i.e. 85/10/5, 85/5/10 (PP/kenaf/PET) were prepared.

The weighed compound of recycled hybrid composite was charged into mould cavity. The recycled material was fabricated into test specimens via compression moulding. Then, tensile and flexural tests were performed. Samples post tensile test were further examined under FESEM machine to analyze the microstructure. Figure 3-1 shows the flow chart of project activities while Figure 3-2 presents key milestones and project activities of FYP 1 and FYP 2.

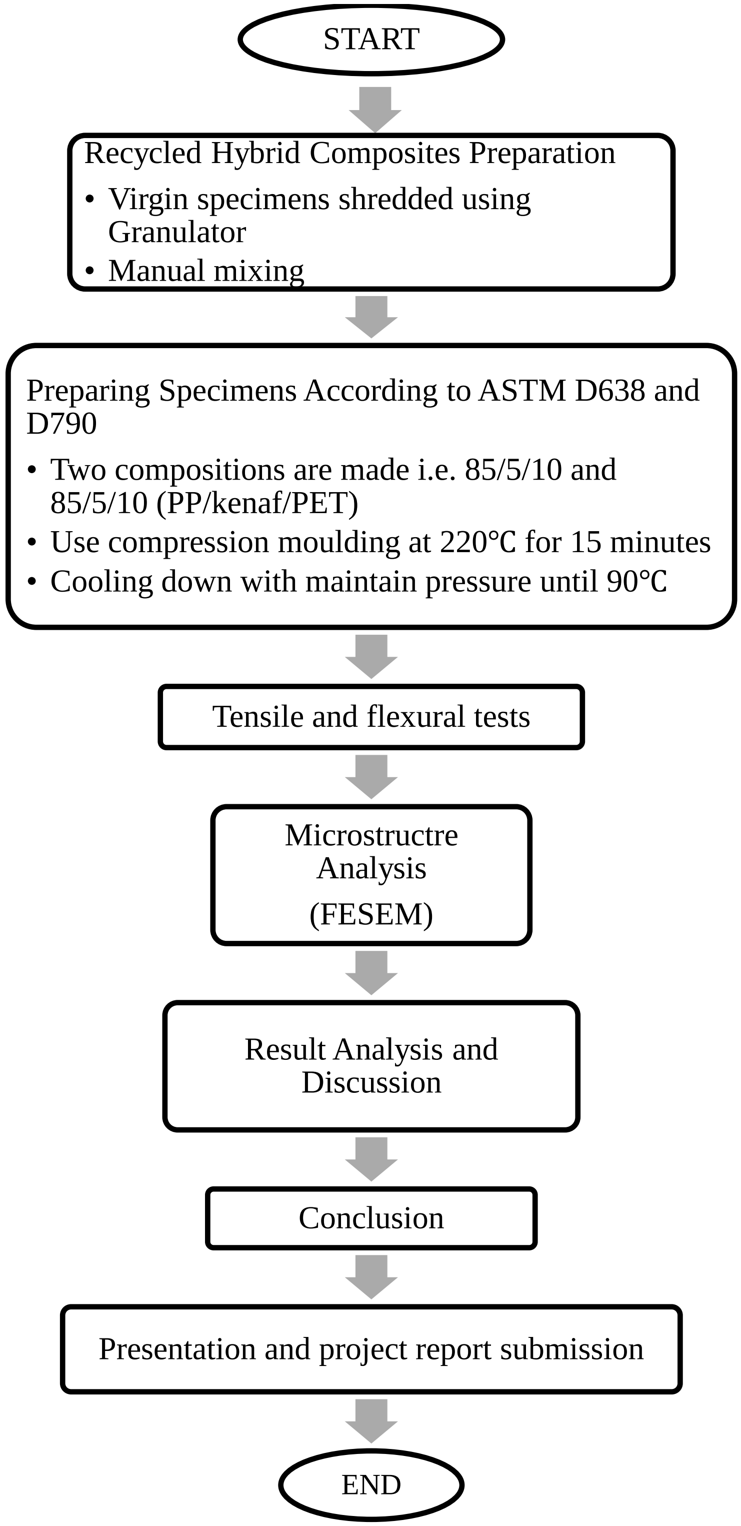


Figure 3-1: Flow chart of project activities.

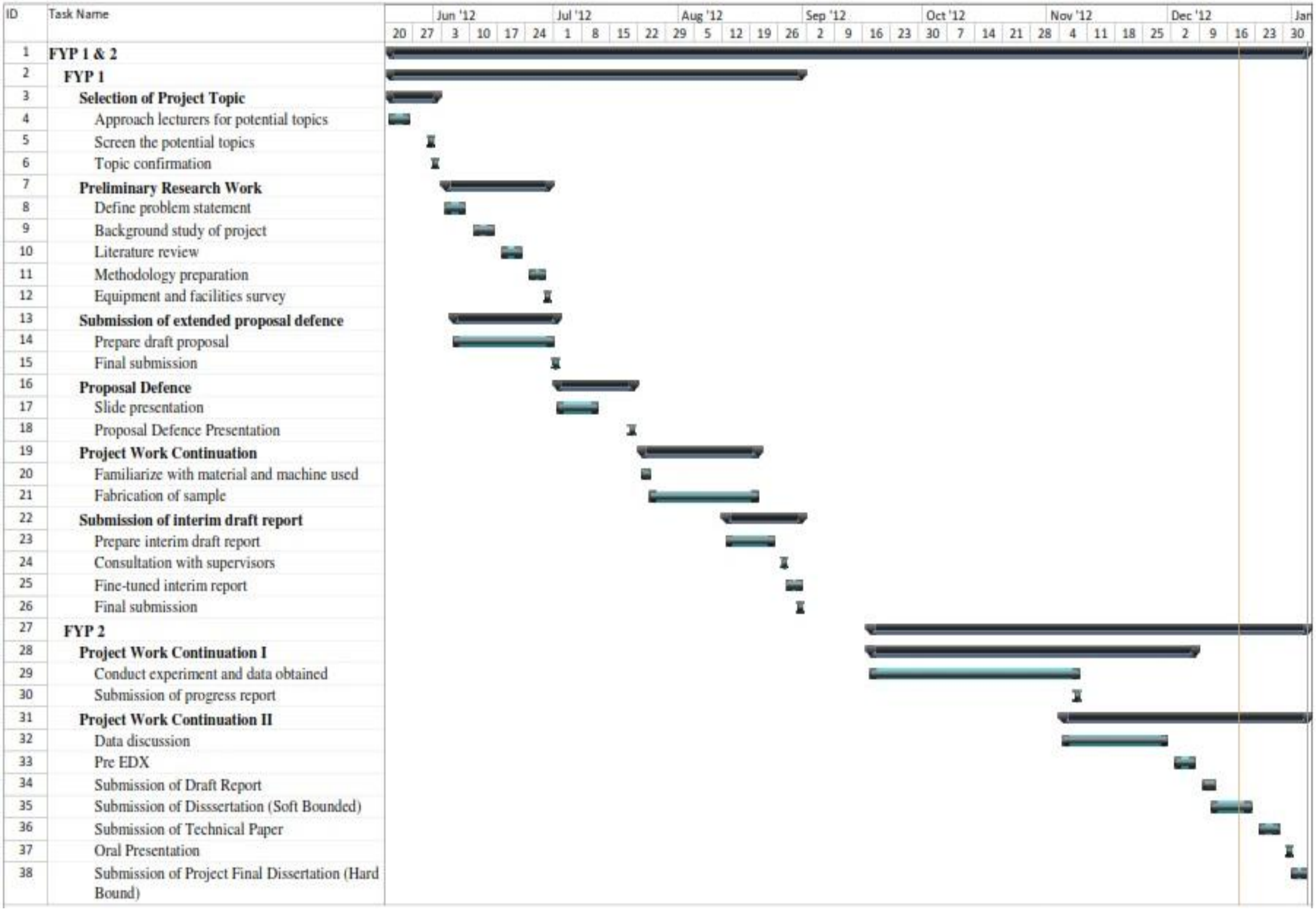


Figure 3-2: Project activities and key milestones for FYP 1 and FYP 2.

3.2 Composite composition

The amount of the reinforcements and matrix is calculated based on the concept of rule of mixture. Equation 3 can be used to calculate theoretical value for ρ_c.

$$\boldsymbol{\rho_c = \rho_m V_m + \rho_{f1} V_{f1} + \rho_{f1} V_{f1}} \text{..................Equation 3}$$

where ρ_c is the density of composite

ρ_m is density of matrix

ρ_f is the density of matrix

The compositions of recycled hybrid composites were exactly the same as virgin hybrid composites. The composition was made based on weight percentage (wt.%) and the volume percentage (vol.%) was obtained by utilizing Equation 3. The virgin composite was a long fiber composite. For recycled composites, the specimens were divided into 2 parts which were with and without coupling agent. Once the composite was recycled, it became a short fiber composite.

3.3 Material used

The natural fiber consumed in this study was long kenaf fiber supplied by Innovative Pultrusion Sdn. Bhd. The material for matrix was polypropylene homopolymer pallets supplied by Titan Petchem (M) Sdn. Bhd. The coupling agent used was an anhydride modified PP, Fusabond ® resin P-613 supplied by DuPont Packaging & Industrial Polymers, Malaysia.

3.4 Preparation of composites

The preparation of composite was done in two stages which are virgin PP/kenaf/PET hybrid composites and recycled PP/kenaf/PET hybrid composites.

3.4.1 Virgin PP/kenaf/PET hybrid composites

The composite was prepared by using sandwich technique where the reinforcement was kept in between the two layers of PP. The layers were made by weighing 8 g of PP pellets using electronic weighing machine. The pellets were put into the mould cavity. The compression machine was first preheated for 10 minutes. With temperature of 180℃ and pressure of 1.6 MPa, the pallets were compressed for 15 minutes. Then, it was allowed to cool until it reached temperature of 90℃. Finally, demoulding process took place. The composite specimens were compression moulded on a Carver Inc. CMG30H-15-CPX at temperature 220℃. The same procedures for making a layer of PP were applied for the composite. The overall process is shown in Figure 3-3.

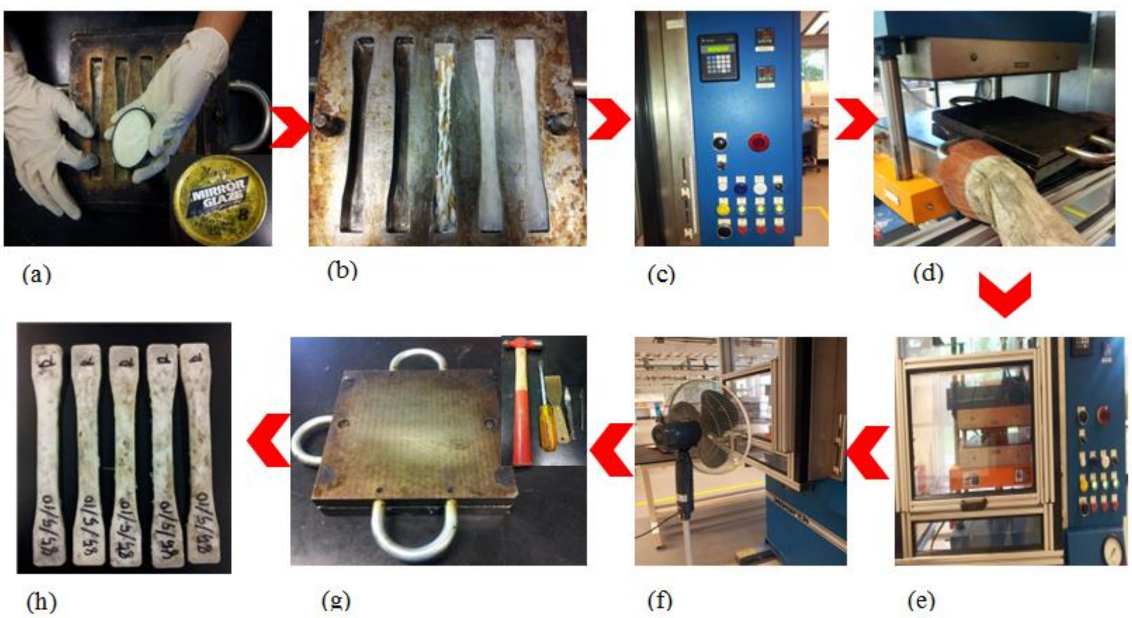


Figure 3-3: Fabrication process (a) mould greasing, (b) mould filling, (c) parameter set-up, (d) mould preheating, (e) heating under compression, (f) cooling under compression, (g) mould detaching, (h) finished product.

3.4.2 Recycled PP/kenaf/PET hybrid composites

After the testing of all specimens, the tested composite were shredded to form raw material for recycled composites. Using Low Speed Granulator SG 16-21 (Figure 3-4), all broken composites were fed into the machine to produce granulates. The same procedures used to fabricate virgin composite were applied to produce recycled composite. Fluffy granulates were observed in both compositions (i.e. 85/5/10 and 85/10/5). However, more fluffiness was observed in 85/5/10 composition due to higher content of PET. It is important to mix the shredded material so that all matrix and fibers distributed well when remaking the composite specimens. The processing temperature was optimized during compression stage.

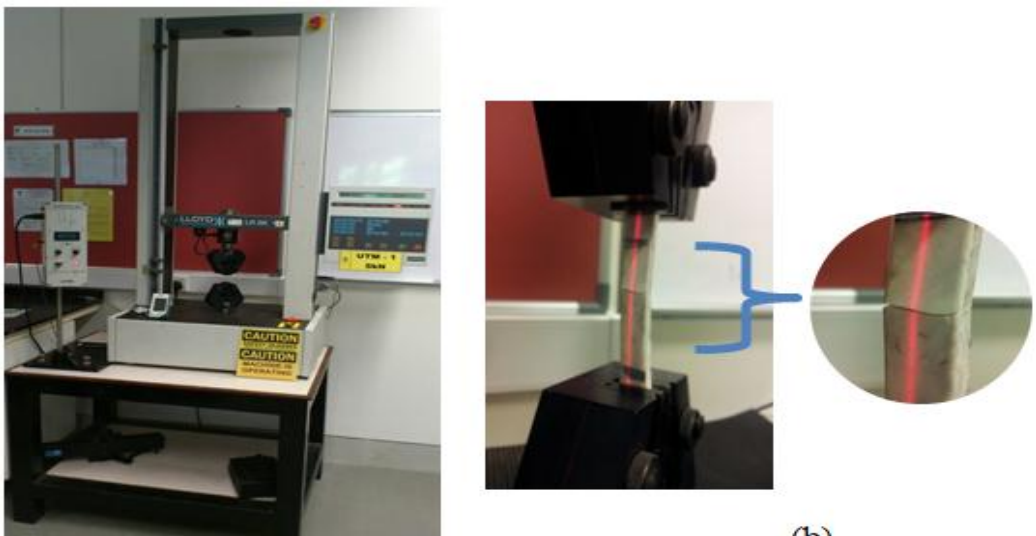
Figure 3-4: Raw materials making.

During the production of recycled hybrid composites, the coupling agent (MAPP) as shown in Figure 3-5 was employed by mixing it randomly with the composites.

Figure 3-5: MAPP pallets.

3.5 Tensile test

The tensile test consists of applying a constant strain on the fibers then measure the load under the parameter condition set by the standard ASTM D638 under the room temperature and humidity with Universal Testing Machine LLOYD. The loading speed was 2 mm/minutes. To tighten the gripper and prevent slipping from happening during the testing, a constant preload was applied for 5 seconds at the initial of the testing. The neck of specimens to-be-tested was scratched down to give enough friction to the gripper to prevent slippage. Figure 3-6 shows Universal Tensile Machine LLOYD with maximum loading of 5 kN.



(b)

(a)

Figure 3-6: (a) Specimen under testing, (b) Specimen under failure.

All tensile specimens for every virgin composites composition were successfully tested. However, there were several cases where the specimens broke at outer range of gauge length. The failed specimens were suspected to have voids outside the gauge. Stress-strain curve, presented in Figure 3-7, shows the response of the composite being under applied stress. Fundamental information such as elastic modulus and yield stress were obtained in the curve. This curve was produced by stretching the specimen at a constant rate.

The polymer stress-strain curve consists of distinct regions namely elastic, yield, necking, cold drawing, strain hardening and failure. During cold drawing phase, the neck extends at which turn polymer chains unravel, aligning themselves parallel to the direction of the applied stress and lead to strain hardening phase. This phase occurs once the whole sample is necked. The stress rises until fracture takes place. Strain hardening is principally a consequence of chain orientation resulting a significantly stronger and stiffer covalent bonding, hence it can receive more stress until eventually it falls down at tensile breaking strength (σ_B).

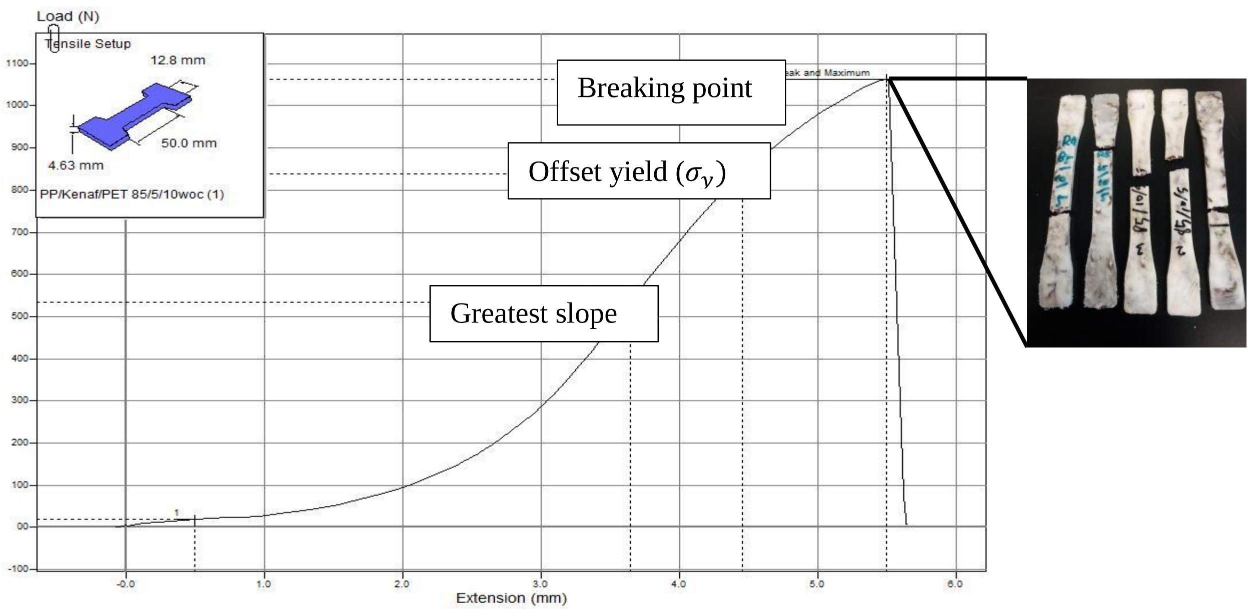


Figure 3-7: Composite stress-strain curve.

3.6 Flexural test

For flexural test, it was conducted under the same machine, Universal Testing Machine LLOYD. The test was governed by ASTM D790 standard. The specimen was placed onto two supports having a 40 mm span length between the supports. The crosshead speed was set to 10 mm/minute. Figure 3-8 shows a specimen underwent bending during flexural test.

Figure 3-8: Specimen under flexural testing.

3.7 Field-Emission Scanning Electron Microscope (FESEM)

FESEM (model SUPRA SSVP®) was used to observe the morphology of the tested specimens as shown in Figure 3-9. This approach gives better information on the interaction of matrix and fibers in composite after being load- applied in microstructure level. Moreover, the effect of coupling agent can be verified.

Figure 3-9: Field-Emission Scanning Electron Microscope (FESEM).

CHAPTER 4

RESULT AND DISCUSSION

4.1 Analytical result

The analytical results were calculated using the rule of mixture. Sample of calculation is shown below. It is assumed that the composite is in perfect interfacial bonding with no void. Figure 4-1 shows the analytical results for tensile properties. As expected the composites show better performance analytically. The strength and modulus data were tabulated in Table A-1 (Appendix).

Sample calculation

$$\sigma_c = \sigma_m f_m + \sigma_{f1} f_{f1} + \sigma_{f2} \sigma_{f2}$$

$$\sigma_c = (40\ MPa)(0.85) + (295\ MPa)(0.1) + (55\ MPa)(0.05)$$

$$\sigma_c = 66.25\ MPa$$

$$E_c = E_m f_m + E_{f1} f_{f1} + E_{f2} \sigma_{f2}$$

$$E_c = (1.9\ GPa)(0.85) + (22\ GPa)(0.1) + (2.7\ GPa)(0.05)$$

$$E_c = 3.95\ GPa$$

$$\sigma_{max} = \sigma_c \times \frac{E_{f1} + E_{f2}}{E_c}$$

$$\sigma_{max} = 66.25\ MPa \times \frac{(22 + 2.7)\ GPa}{3.95\ GPa}$$

$$\sigma_{max} = 103.84\ MPa$$

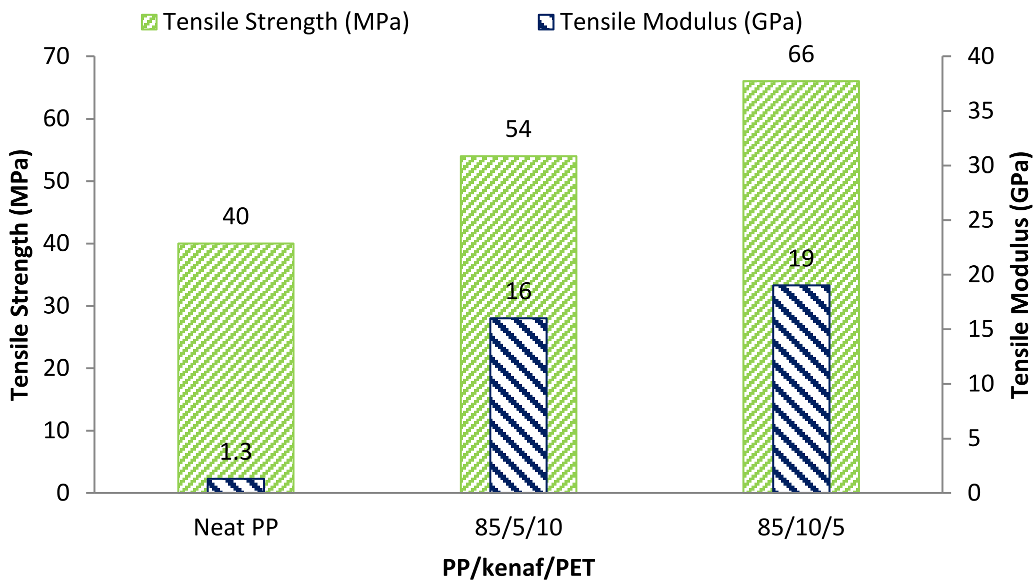


Figure 4-1: Analytical results for tensile properties.

4.2 Tensile properties

The recorded strengths and moduli of the specimens were tabulated in Tables A-2 and A-3 (Appendix). Figures 4-2 and 4-3 show tensile strengths and moduli of the tested specimens, respectively. Tensile strength and modulus of 85/5/10 recycled hybrid composite decreased by approximately 30% and 17% compared to virgin hybrid composite, respectively. Meanwhile, tensile strength and modulus of 85/10/5 recycled hybrid composite decreased by approximately 35% and 20% compared to virgin hybrid composite, respectively.

An increment of approximately 20% was observed for both compositions compared to neat LDPE. A decrement of approximately 10% in both properties was observed for both compositions compared to neat PP. The recycled hybrid composite with coupling agent (WC) showed a decrement of approximately 1% compared to that of without coupling agent (WoC) in both properties.

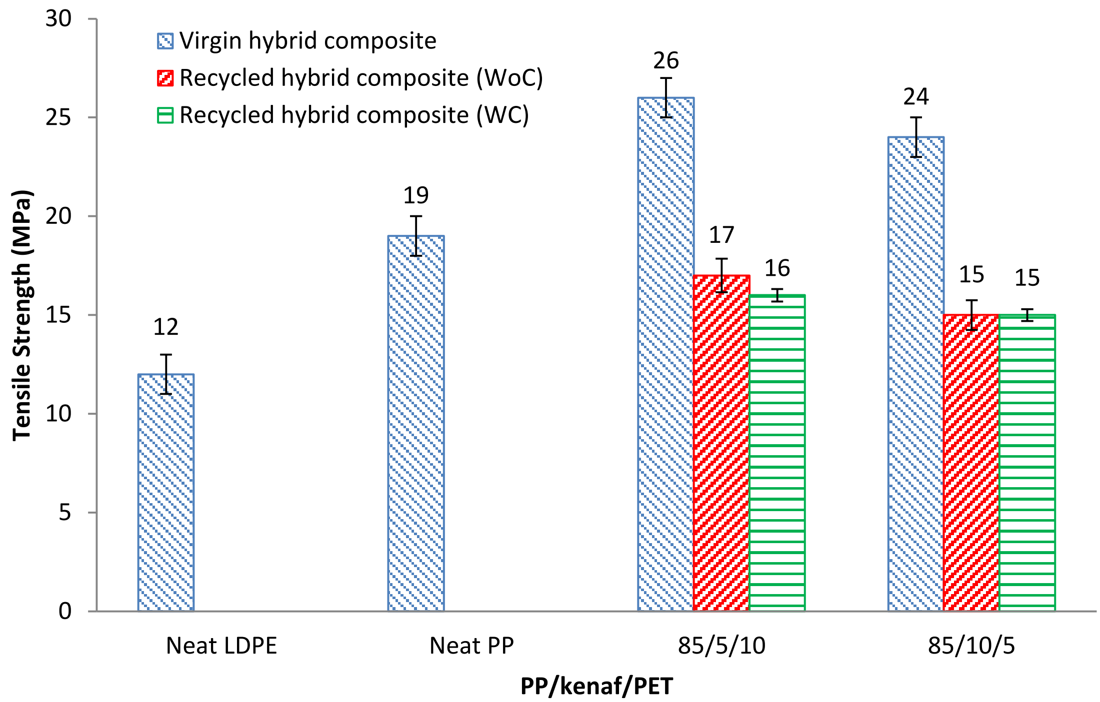


Figure 4-2: Comparison of tensile strengths.

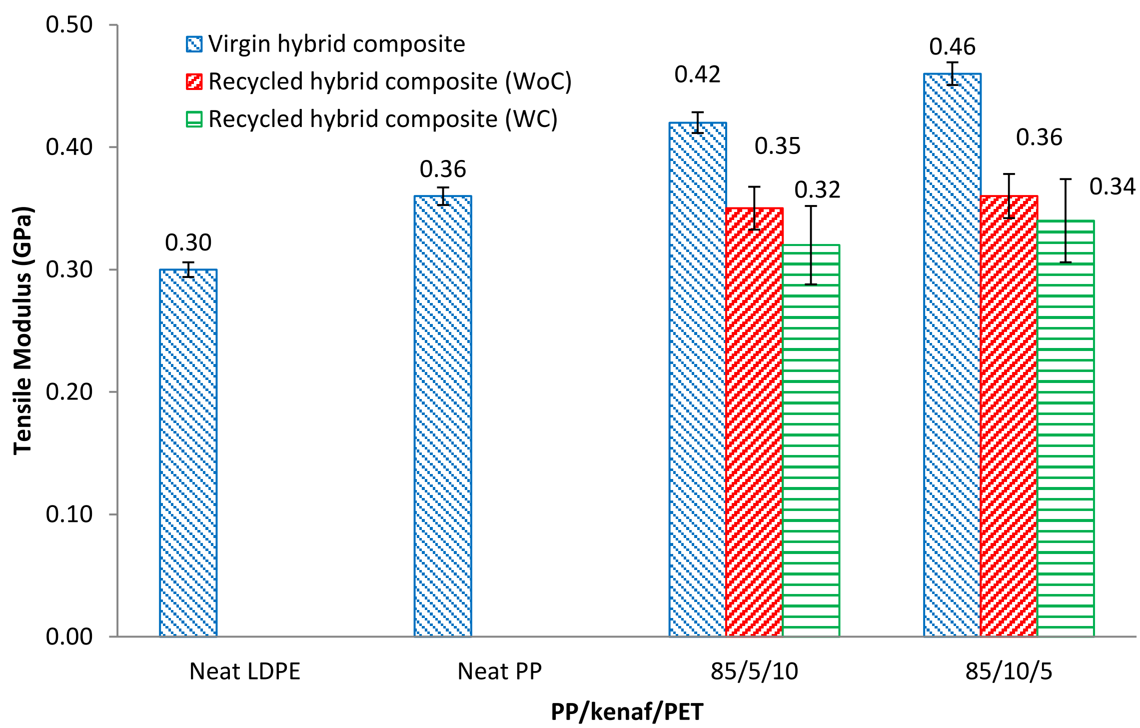


Figure 4-3: Comparison of tensile moduli.

4.3 Flexural properties

The recorded strengths and moduli of the specimens were tabulated in Tables A-4 and A-5 (Appendix). Figures 4-4 and 4-5 show flexural strengths and moduli of the tested specimens, respectively. Flexural strength and modulus of 85/5/10 recycled hybrid composite decreased by approximately 30% and 10% compared to virgin hybrid composite, respectively. Flexural strength of 85/10/5 recycled hybrid composite decreased by approximately 20% while an increment of 50% was observed in flexural modulus compared to virgin hybrid composite, respectively.

An increment of 10% of both properties was observed for both compositions compared to neat LDPE. A decrement of 15% and an increment of 6% were observed in flexural strength and modulus for both compositions compared to neat PP, respectively. The recycled hybrid composite with coupling agent showed a decrement of 10% compared to that of without coupling agent.

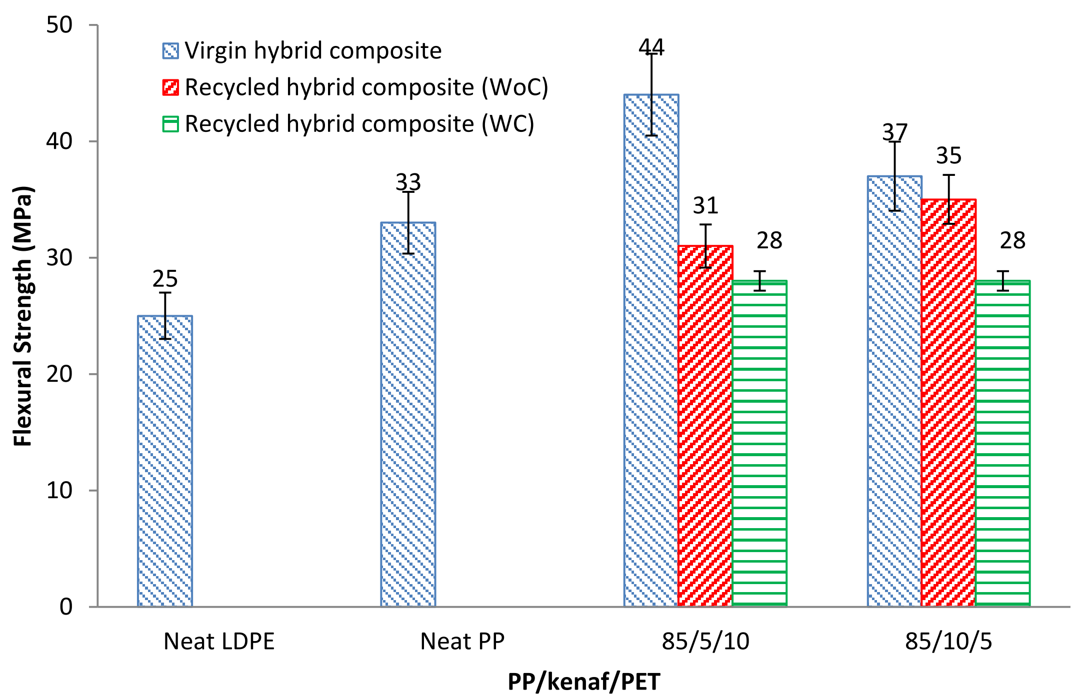


Figure 4-4: Comparison of flexural strengths.

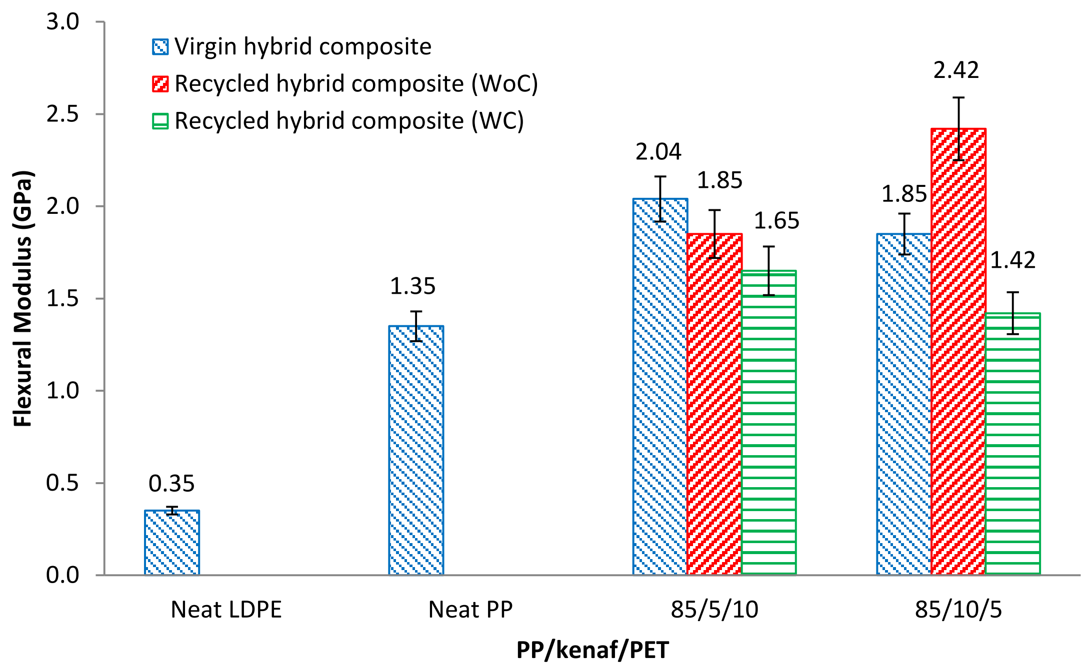


Figure 4-5: Comparison of flexural moduli.

4.4 Discussion

As expected, the experimental tensile strengths and moduli were much lower than that of analytical results. This is due to the experimental specimens have voids and lack of interfacial bonding.

The high decrement of tensile and flexural properties may be due to the damage fibers indicated by the fluffy composites, suggesting that the granulator blade failed to cut the composites fully and cleanly. Figure 4-6 shows samples of ‘fluffy’ composite of both compositions. The blunt cutter will beat the fiber continuously and force the fiber to pass through. The illustration of the condition of the fiber is shown in Figure 4-7. FESEM micrographs were taken to study morphological characteristics to reveal the surface condition of the specimens. Figure 4-8 (a) shows series of defect at fiber reinforcement.

The poor performance of coupling agent may be due to the significant difference of the quantity of the matrix and fiber. Since melt blending process (compounding by extruder) was not done, the possibility of coupling agent to be place in between matrix and fiber is minimum. As a result, some of the coupling agents fall within the matrix, causing slippage and weaken the matrix. Figure 4-8 (b) shows fiber pull-out, indicating poor bonding between matrix and fiber. Similar blend ratio between matrix and fiber should provide high probability of coupling agent to be in between matrix and fiber. Unbalanced blend ratio may decrease the tendency of coupling agent to be in between matrix and matrix, leading to slippage. The application of coupling agent in composite largely depends on polymer processing method. The sturdy and fixed cavity in compression moulding requires different approach for the coupling agent to seep in between matrix and fiber. Fiber coated with fine particles of coupling agents can possibly ensure that the coupling agent would be in between the fiber and matrix.

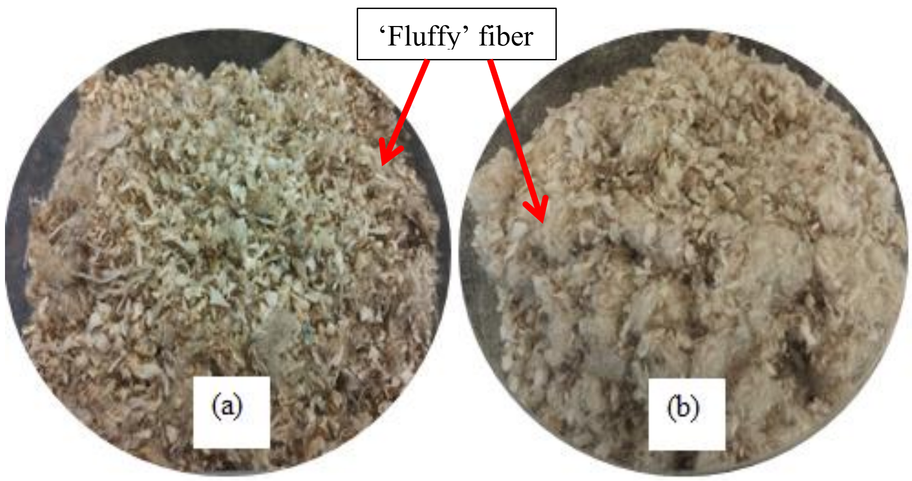


Figure 4-6: 'fluffy' fiber mix.

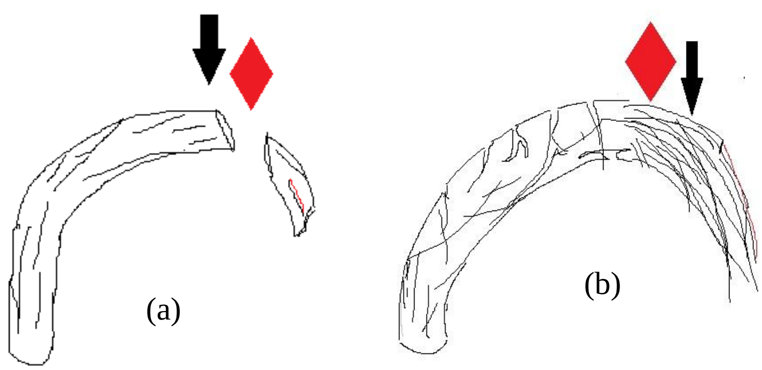


Figure 4-7: (a) Clean-cut-through (b) Damage done by blunt cutter.

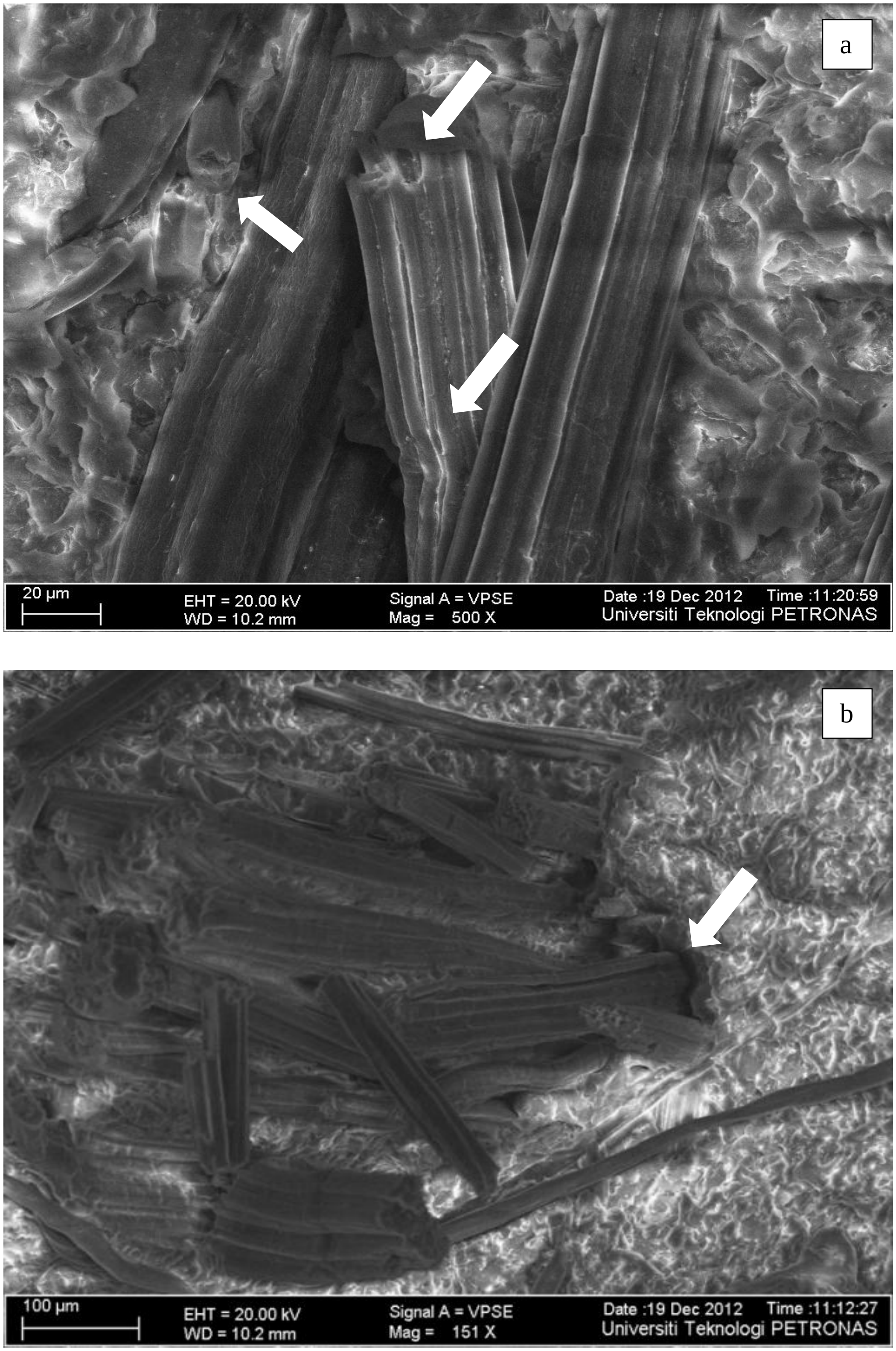


Figure 4-8: FESEM micrograph of 85/10/5 composition with coupling agent, (a) Series of defect on the fiber's surface, (b) Fiber pulled-out.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The objective of the study was achieved. The recycled hybrid composites were successfully fabricated via compression moulding. The experimental result of tensile and flexural properties of recycled hybrid composite showed a reduction of approximately 30% compared to virgin hybrid composite. Coupling agent inflicted an adverse effect to the tensile and flexural properties of the recycled hybrid composite. FESEM images proved that reinforcement had failed to provide strength to the composite. Despite the properties decrement recorded, the tensile and flexural properties of the recycled PP/kenaf/PET hybrid composite were better than that of neat LDPE, suggesting that the recycled composite could be used to replace certain products of LDPE.

5.2 Recommendations

The shredding process should have been given better attention to prevent any rupture or damage to the reinforcement which reduces its strength. The shredding of recycled composite should have been done using sharper blade to ensure full and clean cut-through. For recycled composite processing, the use of extruder machine should assist the composite to blend with the coupling agent. This will ensure better dispersion of coupling agent in the composite. Injection moulded specimens may produce better mechanical properties compared to compression moulded samples since the working principal of injection moulding encourages better dispersion of coupling agent in the composite.

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APPENDICES

Table A-1: Analytical calculation result.

Sample	Volume Fraction %			Hybrid Composite			
	PP	Kenaf	PET	σ_s (Mpa)	E (Gpa)	σ_{max} (Mpa)	σ_{Fs} (Mpa)
1	85	10	5	*66.25	3.95	103.84	0.4
2	85	5	10	54.25	2.99	103.84	0.4

Table A-2: Result of tensile strength.

Sample	**Tensile Strength (MPa)**			
	85/5/10 recycled hybrid composite	85/10/5 recycled hybrid composite	85/5/10 recycled hybrid composite with coupling agent	85/10/5 recycled hybrid composite with coupling agent
1	18.02	14.52	18.80	14.78
2	17.71	16.16	13.85	15.13
3	17.97	15.62	17.47	14.73
4	15.19	15.48	13.97	14.96
5	17.56	15.00	-	-
Avg	17.29	15.36	16.02	14.90
Std	1.19	0.62	2.49	0.18

Table A-3: Result of tensile modulus.

Sample	**Tensile Modulus (GPa)**			
	85/5/10 recycled hybrid composite	85/10/5 recycled hybrid composite	85/5/10 recycled hybrid composite with coupling agent	85/10/5 recycled hybrid composite with coupling agent
1	0.360	0.297	0.305	0.322
2	0.349	0.330	0.308	0.372
3	0.364	0.427	0.365	0.306
4	0.363	0.319	0.302	0.375
5	0.322	0.407	-	-
Avg	0.352	0.356	0.320	0.344
Std	0.017	0.05	0.030	0.034

Table A-4: Result of flexural strength.

Sample	Flexural Strength (MPa)			
	85/5/10 recycled hybrid composite	85/10/5 recycled hybrid composite	85/5/10 recycled hybrid composite with coupling agent	85/10/5 recycled hybrid composite with coupling agent
1	30.49	38.68	27.14	22.44
2	34.44	34.97	28.82	32.62
3	28.90	34.12	36.43	25.13
4	32.16	34.14	30.06	32.30
5	30.12	32.30	-	29.64
Avg	31.22	34.84	30.61	28.43
Std	2.14	2.36	4.06	4.49

Table A-5: Result of flexural modulus.

Sample	Flexural Modulus (GPa)			
	85/5/10 recycled hybrid composite	85/10/5 recycled hybrid composite	85/5/10 recycled hybrid composite with coupling agent	85/10/5 recycled hybrid composite with coupling agent
1	1.616	2.364	1.573	1.423
2	1.680	2.198	1.615	1.603
3	1.645	1.920	1.810	1.208.
4	2.117	2.883	1.581	1.395
5	2.165	2.722	-	1.450
Avg	1.845	2.417	1.645	1.416
Std	0.271	0.389	0.111	0.141