Mechanical Properties of Oil Palm Empty Fruit Bunch (EFB) – High Density Polyethene (HDPE): Influence Of Processing Techniques

by

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

JANUARY 2009

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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 fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL ENGINEERING)

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January 2009

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.

Muhamad Aizat Bin Muhamad Yunos

Abstract

The objective of the project is to investigate the effects of varying processing techniques on tensile properties and flexural properties of empty fruit bunch (EFB) - high density polyethylene (HDPE) composites. Dried empty fruit bunch fiber of 5 mm in length was compounded with HDPE matrix using extruder machine at 150°C. The resulting compound is further processed using either an injection molding or compression molding to obtain the tensile test bars. Samples obtained from both processing techniques were subjected to tensile test and flexural test. Finally, the tensile properties and flexural properties obtained from both processing techniques were analyzed and compared. The samples from injection molding process exhibited better tensile properties and flexural properties compared to those fabricated using compression molding. This was due to pore spaces or voids within the compression molding samples. Furthermore, the voids between the EFB fibers and HDPE matrix could also be the reason for poor mechanical properties of both injection molded and compression molded samples. The effect of EFB fiber were negligible in tensile test, but it shown a large significant in flexural strength as the percentage difference of flexural strength and flexural modulus showed the highest in each properties with value of 31% and 30%. These results indicate that processing technique does have an influence on the mechanical properties of the EFB-HDPE composites.

ACKNOWLEDGEMENT

First and foremost, all praises and thanks to Allah, the almighty God, the source of my life and hope for giving me the wisdom to succeed in life.

I would like to thank my supervisor, AP Dr. Puteri Sri Melor Megat Yusoff, for her great support and commitment in ensuring the success of this project. All of her advice and guidance were highly appreciated.

I would also like to thank the UTP technician: En. Shairul, En. Anuar, En. Zamri, En. Faisal and En. Irwan for their help regarding with the processing and testing machine.

Finally, this project shall not be completed without the support of my family. I would like thank my mom, Pn. Zaiton Binti Yahaya and my dad, En. Yunos Bin Koming for their endless love and support.

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LIST OF ABBREVIATIONS

EFB	Empty Fruit Bunch
HDPE	High Density Polyethylene
ICI	Imperial Chemical Industries
LDPE	Low Density Polyethylene

LIST OF NOMENCLATURES

b	Width of the specimen
C	Carbon atom
d	Height of the specimen
E_{bend}	Flexural Modulus
F_f	Load of fracture
H	Hydrogen atom
L	Distance between support points
n	Molecular weight
R	Crosshead motion of the testing machine
δ	Deflection of the beam
σ_{fs}	Flexural strength

Chapter 1

Introduction

1.1 Background

The polyethylene material have been discovered by the Reginald Gibson and Eric Fawcett at the British Industrial Giant Imperial Chemical Industries (ICI) in 1933, where there were two types of polyethylene which is the low density polyethylene (LDPE) and high density polyethylene (HDPE) [1]. Since then, a lot of research and technology development have been carried out in order to obtain and understand the mechanical properties of the plastic material. HDPE materials have a few advantages which are economical, strong and chemical resistant. Therefore, it is being used in most manufacturing industries all around the world to produce consumers' product and machinery items for example, containers, piping materials and automotive fittings. After the discovery of plastic material, a new approach of combining the high density polyethylene material with natural fiber such as empty fruit bunch have been carried out in order to obtain a better mechanical properties of the newly developed fiber composite. During the combination between empty fruit bunch with HDPE, various processing techniques, such as injection molding and compression molding, can be apply in order to obtain a new fiber-filled composite.

1.2 Advantages Of Natural Fibers

Natural fibers such as oil palm empty fruit bunch and kenaf have been widely used in most of manufacturing industries due to its low specific weight where a higher specific strength and stiffness can be obtained. Therefore, it is an advantage especially for parts design industry and automotive dashboard production as it requires stiffer materials. Since the oil palm empty fruit bunch fiber is classified as a biomass product, it can be easily obtained and at low cost.

Moreover, it is a renewable source where it can be widely commercialized and also the production of natural fiber composites requires small amount of energy [2]. During the production phase, the processing techniques employed can influence the mechanical properties of the empty fruit bunch – HDPE composite and therefore affect the advantages of the fiber composite.

1.3 Processing Of Natural Fiber Composites

The combination of oil palm empty fruit bunch and HDPE will require processing phase in order to obtain the natural fiber composite. The processing technique that will be used during the research is injection molding and compression molding. Injection molding is a manufacturing process for producing parts from polymeric materials. Molten EFB-HDPE composite is injected at high pressure into a mold, which is the inverse of the product's shape. Most of the injection molding that is being used nowadays uses screws to increase the efficiency of heating, mixing and injecting the natural fiber composite into molds [3]. Another processing parameter that can be used to create natural fiber composite is the compression molding where, high force and pressure will be applied to ensure that the fiber composite material are in contact with all mold areas. An advantage of applying the compression molding method is that it produces less fiber-length degradation than injection molding method [4].

1.4 Problem Statement

Various research have revealed that the mechanical properties of empty fruit bunch – HDPE composites such as tensile modulus increased, whereas tensile strength and impact strength decreased with increasing filler loading. Unfortunately, mechanical properties of most materials will change after they are being processed. Apart from the filler loading there are other factors that affect the mechanical properties of fiber composites such as fiber length, chemical treatment and temperature used during the processing phase. However, the effect of processing parameters on mechanical properties of composites requires further investigation. The processing parameters will affect the microstructure of the composites particularly the fiber orientation and its distribution.

The changes in microstructure of fiber filled composite can influence the mechanical properties of the newly developed material which includes tensile strength and flexural strength. This study particularly will investigate the effects of processing techniques on the mechanical properties of the empty fruit bunch – HDPE composites.

1.5 Objectives and Scope of Study

The objective of this project is to investigate the effect of different processing techniques such as compression molding and injection molding on mechanical properties of the empty fruit bunch-HDPE composite. The mechanical properties that will be investigated in this project are tensile properties and flexural properties of the natural fiber composite after it undergoes particular processing technique. The material used in this project is the oil palm empty fruit bunch and high density polyethylene matrix where they were combined to produce natural fiber composite.

Chapter 2

Literature Review and Theory

2.1 Previous Related Research

Besides processing techniques, the mechanical properties of EFB-HDPE composite can be influenced by other factors such as fiber length, fiber content and chemical treatment that are being applied on the natural fiber composite. An example of the previous related research that have been done was the investigation of oil palm empty fruit bunch composites based on high density polyethylene matrix. In the research, the effect of EFB fiber content, fiber length and chemical treatment on mechanical and water absorption properties of the composites was investigated. The research showed that the EFB short fiber composites have high tensile and flexural properties compared to EFB particulate composites. The increase of EFB content increased the flexural modulus but decreased the tensile strength of EFB short fiber composites and EFB particulate fiber composites [5]. The research is related to this study where the same natural fiber material is being used to investigate the effect of certain parameters on the mechanical properties of the natural fiber composites [6].

Another related research that have been done was the study of influence of processing methods and fiber length on physical properties of kenaf fiber reinforced soy based, where the same processing techniques of injection molding and compression molding were being used to investigate the influence of processing parameters [7]. Various fiber lengths is being used to examine the effect of fiber size. The research showned that the compression molded sample of kenaf fiber reinforced say based composites had similar storage modulus to the injection molded sample at room temperature. Moreover, the compression molded sample had a higher Izod impact strength compared to the injection molded sample of the natural fiber composites. Therefore, the research is related to the current investigation where various processing techniques were shown to influence the mechanical properties of natural fiber composites.

There were other related research that has been carried out to investigate on the mechanical properties, deformation and fracture of a natural flax fiber polymer composite. The related research has been carried out using similar processing technique and natural fiber composites which is compression molding and flax fiber high density polyethylene composite [8]. The mechanical properties of the composite that was determined experimentally were tensile strength, tensile (Young's) modulus, ductility and toughness. The mechanical properties of the natural flax fiber polymer composite were being compared between 0%, 10%, 18%, 20% and 30% by volume flax fiber. As a result of the investigation, the material properties showed greater variability at high fiber volume fractions, due to fiber clamping. The research is related to this study where natural fiber composite and similar processing technique has been used to investigate the effect of various fiber volume fractions on mechanical properties of the material.

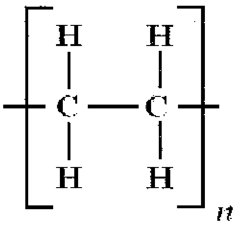
An example of previous related research which used similar composite material is the characterization of wheat straw fibers for reinforcing application in injection molded thermoplastic composites [9]. The objective of the research was to process and characterize wheat straw fibers to evaluate their potential as reinforcing materials for thermoplastics. The wheat straw fibers were prepared by mechanical and chemical process as reinforcing additives. Composites of polypropylene filled with 30% wheat straw fibers were prepared and tensile strength and flexural strength were evaluated. The research showed that composite with mechanically prepared wheat straw fibers yielded 29% and 49% improvement in tensile and flexural strength, whereas composition with chemically processed fiber exhibited 12% and 49% enhancement in tensile and flexural strength. The research is related to this is study since the material used in the investigation is natural composites. Chemically and mechanically processed fiber can affect the mechanical properties of a natural composite.

2.2 High Density Polyethylene

Since the processing technique can influence the microstructure as well as the mechanical properties of the EFB-HDPE, it is important to understand the natural fiber composite and its matrix microstructure. The microstructure of polymers can be characterized either amorphous structure or semi-crystalline structure. Polyethylene varies in molecular weight, branching characteristics and chain orientation.

The chain orientation of polyethylene increases as the density increases causing microstructure to be more crystalline. The crystalline structures of HDPE have regular, straight-chain structure with small pendent group which can be seen in Figure 2.1. Moreover, when HDPE cools from liquid state, the long polymer chains folded up to form a regular, repeating structure which constitutes a crystal [10]. Formation of crystalline structure in HDPE helps to increase resistance to chemical attack and mechanical properties because of strong bonding between the chains. Basically, polyethylene are made from ethylene monomer which undergoes low pressure and low temperature techniques [11].

Improvements of the properties of HDPE matrix have focused on using advance polymerization techniques to tailor the degree of branching and molecular weight distribution. The importance of HDPE matrix improvement is to avoid material failure which is caused by either chain breakage or disentanglement of individual chains from their neighbours [8]. The molecular structure of HDPE atoms are describe as follow:



$$\left[\begin{array}{c} \mathrm{H} \quad \mathrm{H} \\ | \quad\ \ | \\ -\mathrm{C}-\mathrm{C}- \\ | \quad\ \ | \\ \mathrm{H} \quad \mathrm{H} \end{array}\right]_n$$

where H = Hydrogen atom
C = Carbon atom
n = Molecular weight (number of repeating units)
[ ] = Monomer symbol
— = Electron bond

Therefore, the development EFB-HDPE composite is another way to improve the microstructure since it can affect the mechanical properties of the newly developed composite. But, the EFB-HDPE composite microstructure is being influenced by the processing parameters as changes of fiber distribution occur during the processing phase.

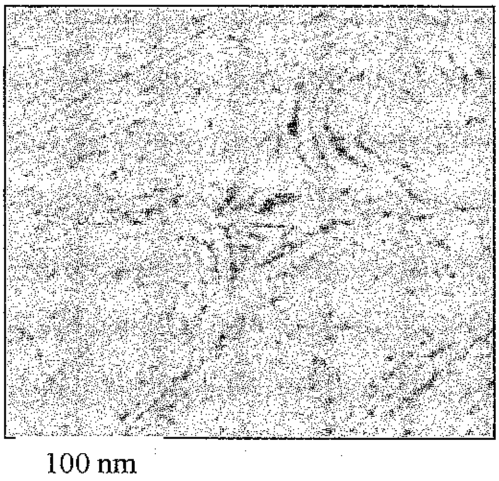


Figure 2.1: Microstructure of High Density Polyethylene [5].

2.3 Tensile strength

Tensile strength is the maximum stress on the engineering stress-strain curve which can be seen in Figure 2.2. This corresponds to the maximum stress that can be sustained by the EFB-HDPE composite specimen in tension. All deformation up to this point is uniform throughout the narrow region of the tensile specimen [12]. Engineering stress- strain curve from each processing technique will be obtained in order to compare and analyze the data.

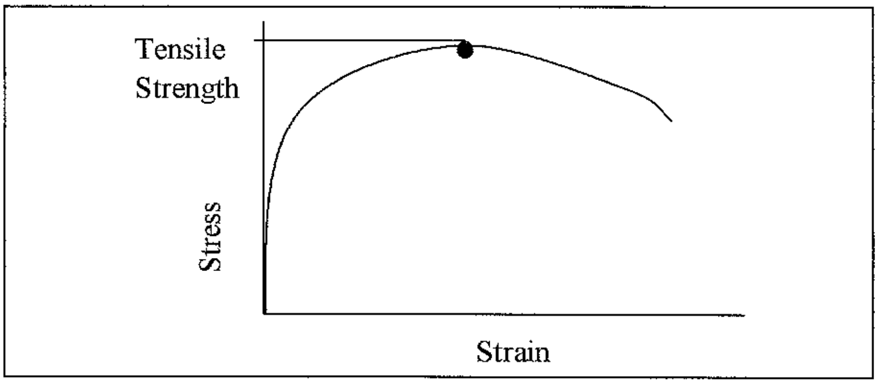


Figure 2.2: Typical maximum tensile strength in engineering stress-strain curve illustration [12].

2.4 Flexural Strength

Another mechanical properties of the natural fiber composite that will be tested is the flexural strength. The stress at fracture using flexure test is known as the flexural strength, modulus of rupture or fracture strength. The specimen will be subjected to a tree-point bending test as shown in Figure 2.3.

The formula for flexural strength of a rectangular cross section is,

$$\sigma_{fs} = \frac{3F_f L}{2bd^2} \tag{1}$$

According to Figure 2.3, F_f is the load of fracture, L is is the distance between support points, d is the height of the specimen and b is the width of the specimen. Moreover, flexural strength, σ_{fs}, will depend on specimen size. With the increasing of specimen volume, there is an increase in the probability of the existence of a crack-producing flaw and, consequently, a decrease in flexural strength [12].

The formula for flexural modulus is,

$$E_{bend} = \frac{L^3 F_f}{4bd^3 \delta} \tag{2}$$

Based in the flexural modulus equation, δ is the deflection of the beam when a force F is applied. According to the ASTM D790 – 03, the flexural properties may vary with the specimen depth, temperature, atmospheric conditions and the difference in the rate of straining. Moreover, the crosshead motion of the machine is being set according to the calculation that have been made by using the equation below,

$$R = \frac{ZL^2}{6d} \tag{3}$$

where,

R = rate of crosshead motion, mm/min,

L = support span, mm,

d = depth of beam, mm,

Z = rate of straining of the outer specimen, mm/mm/min.

According to the ASTM D790 – 03, the rate of straining of the outer specimen, Z, is 0.01 mm/mm/min.

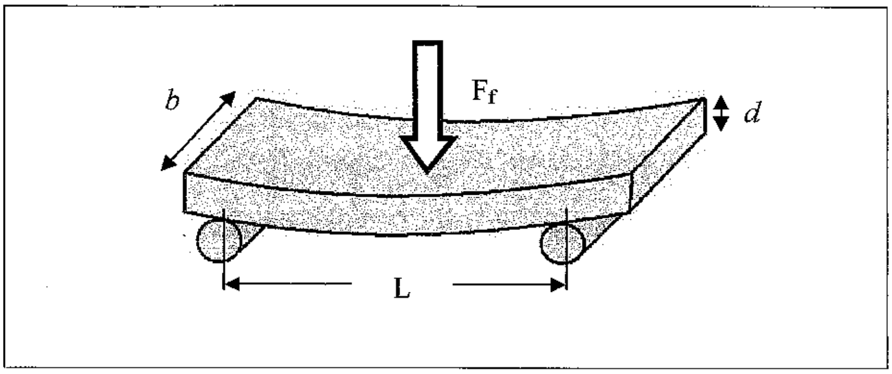


Figure 2.3: 3-point bending test for flexural strength test.

2.5 Processing Theory

High temperature above the melting point was applied during the injection molding process in order to inject the composite material into the mold. In injection molding process, the composites were being fed from a hopper into a heated barrel where it is melted, after which a screw or ram forces the composites into the mold, as shown in Figure 2.4. The temperature condition applied on the composite material on both processing technique can affect its mechanical properties of the samples. The composite material become more brittle as it is being exposed to temperatures that are below its melting point [11].

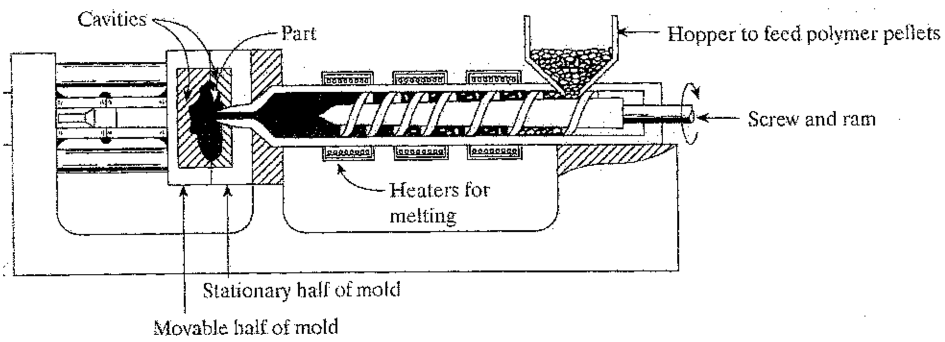


Figure 2.4 Typical schematic diagram of injection molding [10].

For the compression molding process, both mold pieces were heated, causing the composite material to become viscous and flow to conform to the mold shape. The temperature of the upper and lower plate of the compression molding machine must be higher than the melting point of the sample. Both plates will compress the mold according to the compression pressure that has been set after, plates, mold plunger and mold base are equilibrium in temperature, as shown in Figure 2.5. The hydraulic plunger will apply the compression pressure.

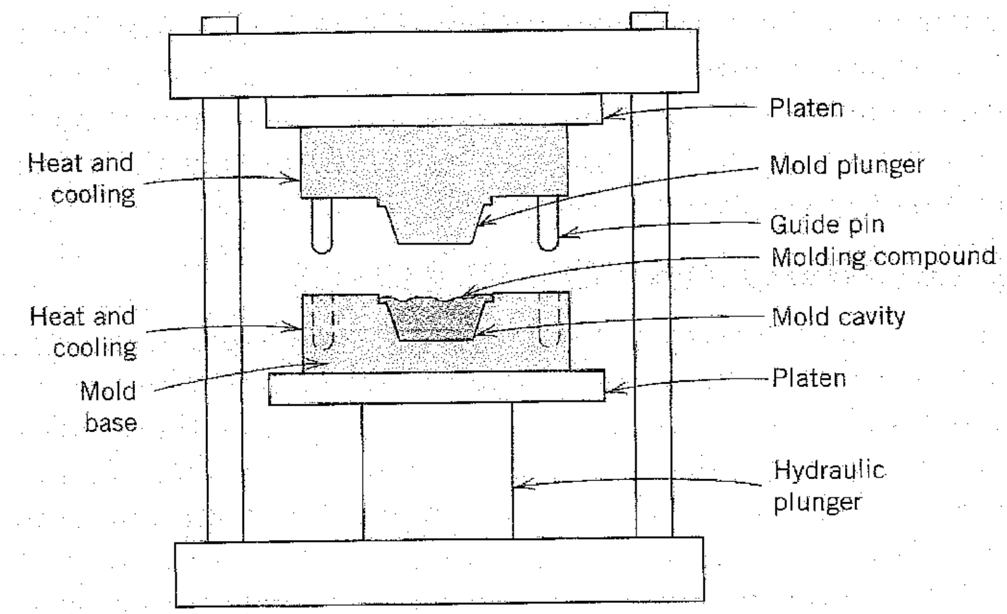


Figure 2.5 Typical schematic diagram of compression molding[12].

Chapter 3

Methodology

3.1 Materials Used

Oil palm empty fruit bunch was obtained from the local farmers in the form of coir and used as the natural fiber. Example of EFB before it is being process into coir is shown in Figure 3.1. The weight of EFB that are being used is about 450 g per bunch. High density polyethylene with density of 0.958 g/cm^3 was purchase from the Titan Chemical Sdn. Bhd.

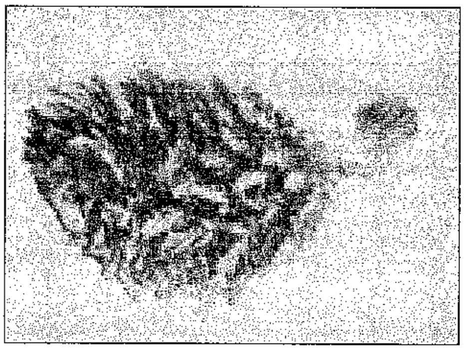


Figure 3.1: Typical Oil Palm Empty Fruit Bunch [9].

3.2 Sample Preparations

3.2.1 Compounding of EFB and HDPE

EFB coir was shredded into particles which have an average fiber length of 5 mm and kept in the oven at 80°C for 12 hours to remove the moisture content as shown in Figure 3.2. The HDPE-EFB composites were compounded with 20%wt EFB fiber content. To obtain EFB-HDPE composites, both EFB fiber and HDPE matrix were fed into the Leistritz extrusion machine with temperature of 140°C for each barrels.

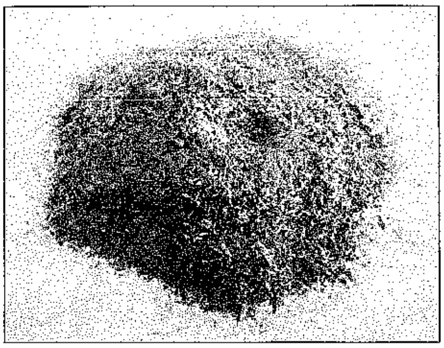


Figure 3.2: 5 mm length of empty fruit bunch

The temperature for the flange and die was being set to 208°C and 210°C respectively so that the EFB-HDPE composites will not solidify at the 2 mm die. The EFB-HDPE composite rod obtained from the Leistritz extrusion machine were shredded into granulates form as shown in Figure 3.3. The compounded granulates were used in the injection molding and compression molding process.

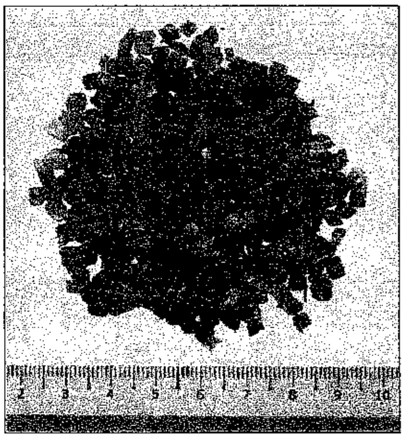


Figure 3.3: EFB-HDPE composites in granulates form

3.2.2 Injection Molding

ME20II Tat Ming Mechatronics injection molding machine has been used to make dog-bone shape specimen for mechanical properties measurements. The EFB-HDPE composites will be injected into the mold cavity with temperature of 170°C and 80 bar of pressure. Duration of the heating process of the injection machine was 30 minutes. Average of 7 dog-bone shape samples of EFB-HDPE composite molding have been obtained for subsequent tensile test in order to analyze the effects on mechanical properties.

3.2.3 Compression Molding

Alternatively, CARVER CMG30H-15-CPX compression molding machine was also used to process and obtain the dog-bone shape specimens. The preheating process was the initial activity before the compression molding. Both heating plate, Platen 1 and Platen 2, were being set at the same temperature of 170°C. The preheating process of the compression molding machine will take 30 minutes. The natural fiber composite were put in the mold cavity which then be closed with top force and of 4 kN. It is assumed that the heat from both plate were transferred to the mold since the effect of surrounding temperature is negligible. This condition was being maintained throughout the process until the EFB-HDPE composite mold was obtained. Average of 7 dog-bone shape samples of EFB-HDPE composite molding were obtained for the next step of the investigation. The overall methodology is as shown in Figure 3.4.

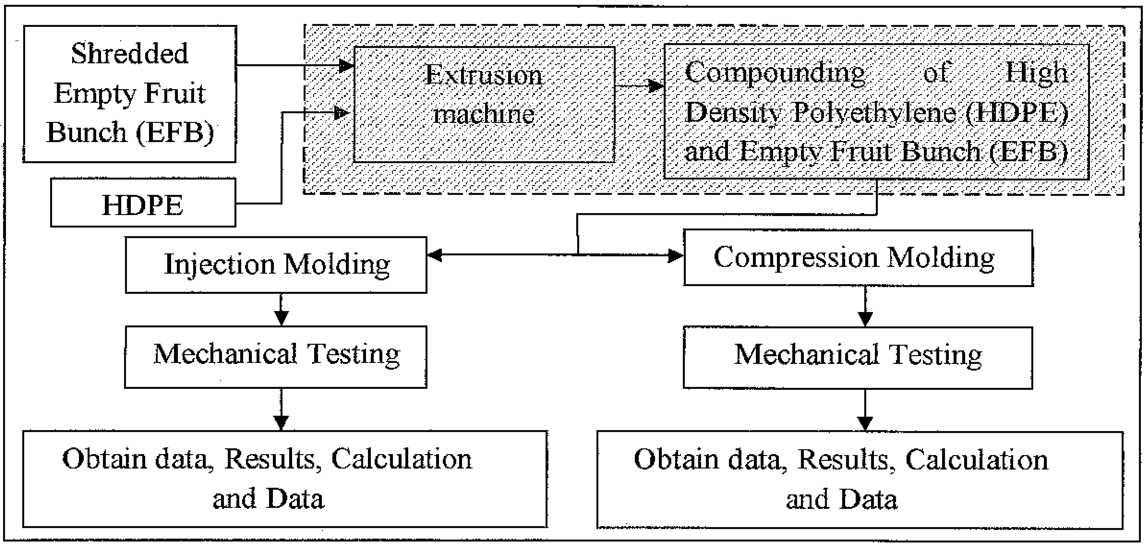


Figure 3.4: Methodology to study the effect of processing technique on mechanical properties.

3.3 Mechanical Testing

3.3.1 Tensile Test

All specimens were prepared according to ASTM D 638 standard. Average of 7 natural fiber composite specimens from each processing technique will then be tested for their tensile strength by using the ARMSLER HA100 Universal Tensile Machine.

The EFB-HDPE composite specimen will be applied with 5 kN of force and strain rate of 5 min^{-1}. Data and results that will be gained from the testing machine will be calculated and compared with that processed by the other processing technique.

3.3.2 Flexural Test

All specimens for flexural test were prepared according to ASTM D 760-03 standard. The conditions of the test specimens temperature and humidity were 23°C and 5% respectively. Average of 7 natural fiber composite specimens from each processing technique were tested for their flexural strength by using the ARMSLER HA100 Universal Tensile Machine. A 5 kN force and were employed. Different dimension of each samples have different strain rate. Data and results obtained from the test were analysed and compared with that processed using the other processing technique.

Chapter 4

Results and Discussion

4.1 Tensile test

Two types of processing technique, injection molding and compression molding were being investigated. Figure 4.1(a) shows the typical stress-strain curve of EFB-HDPE composite sample from injection molding process. The results show that samples of EFB-HDPE composites from injection molding process have a low tensile strength which is an average of 18.3 MPa with standard deviation of 0.7 MPa, compared to pure HDPE of injection molding which is 22.1 MPa [13].

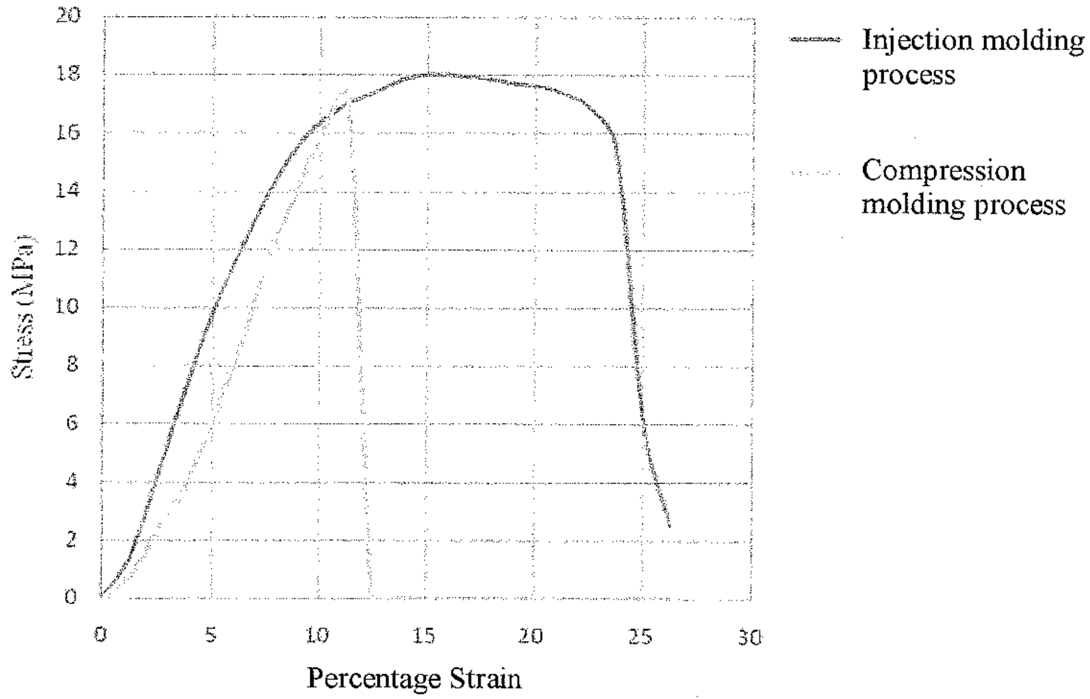


Figure 4.1: Typical stress-strain curve of EFB-HDPE composites prepared by injection molding process and compression molding process.

Tensile test showed that the tensile strength of EFB-HDPE composite samples of compression molding were much lower with the value of 12.6 ± 2 MPa than that of pure HDPE prepared by equivalent processing technique, value of 18.8 MPa with a standard deviation of 2.2 MPa. Its percentage difference was 31%. Figure 4.1(b) shows the typical stress-strain curve of EFB-HDPE composite prepared by compression molding process.

Pure HDPE prepared by injection molding, has a tensile modulus of 1 GPa. Lower tensile modulus of both EFB-HDPE composite samples processes by injection mold and compression mold, with the value of 240.9 MPa ± 11.5 MPa and 269 MPa ± 5.8 MPa, respectively, maybe due to the elastic property of HDPE that have been reduced by the presence of EFB fiber. Stress at yield of EFB-HDPE composites prepared using injection molding samples, with the value of 11.5 MPa ± 0.4 MPa was slightly higher than that of the compression molding samples, with the value of 10.9 MPa ± 0.7 MPa, with a percentage difference of 5%.

It was observed that most of the compression molded samples failed at the pores spaces in the EFB-HDPE composite samples as shown in Figure 4.2(a). The presence of pores, as noted by the faded colour on the surface of the EFB-HDPE composite sample, was expected to decrease the tensile properties of the material. This pores are seen to develop more in the compression molding samples compared to injection molding samples.

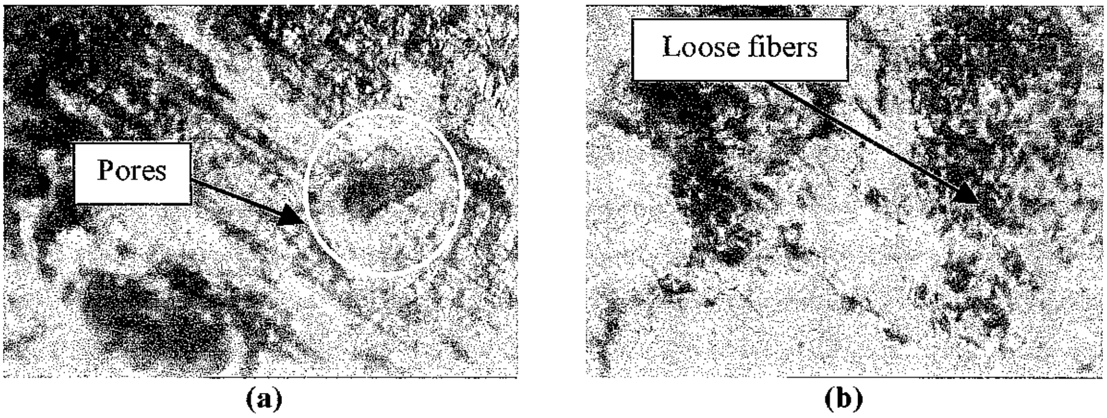
(a) (b)

Figure 4.2: Optical microscopic of the surface of the EFB-HDPE composite prepared using compression molding process with (a) 5 X magnification and (b) 10 X magnification.

The pores in the EFB-HDPE composite samples of compression molding process occur due to gaps between the granulates of natural fiber composites at the earlier process of compression molding. In the pore spaces, huge amount of loose fiber, as shown in Figure 4.2 (b). Loose fibers were EFB fibers that were wrapped with HDPE matrix but with poor bonding between each fiber.

The gaps between granulates of EFB-HDPE composite provide a platform for pores to develop during the compression molding process. The air that was trapped between the gaps will expand throughout the compression molding process due to the heating effect and created larger pores in the natural fiber composite.

Compared to the injection molding, the EFB-HDPE composite has less gaps or pores since it was injected in molten condition as shown in Figure 4.3 (a). There was less loose EFB fiber seen in the pores. The EFB fibers were closely packed and contact with the HDPE matrix. The surface of pores can be seen in Figure 4.3 (b).



(a) (b)

Figure 4.3 : Optical microscopic of surface of EFB-HDPE composite sample prepared using injection molding process with (a) 5 X magnification and (b) 20 X magnification.

4.2 Flexural Test

The highest value for flexural strength was found to occur for the injection molding samples of EFB-HDPE composite which was 33.7 MPa with standard deviation of 1.1 MPa. The flexural strength of injection molded EFB-HDPE composite samples was slightly higher than that of pure HDPE, value of 29.2 MPa ± 1 MPa, but does not show much significant since the variation is only 4.5MPa, as shown in Table 4.1.

The samples of pure HDPE and EFB-HDPE composite which were prepared by using compression molding did not shown much different as the flexural strength of both samples were 24 MPa and 23.1 MPa, respectively. The difference in maximum deflection between pure HDPE and EFB-HDPE composite of injection molding was negligible. The typical stress-deflection curve of EFB-HDPE composite can be referred to Figure 4.4.

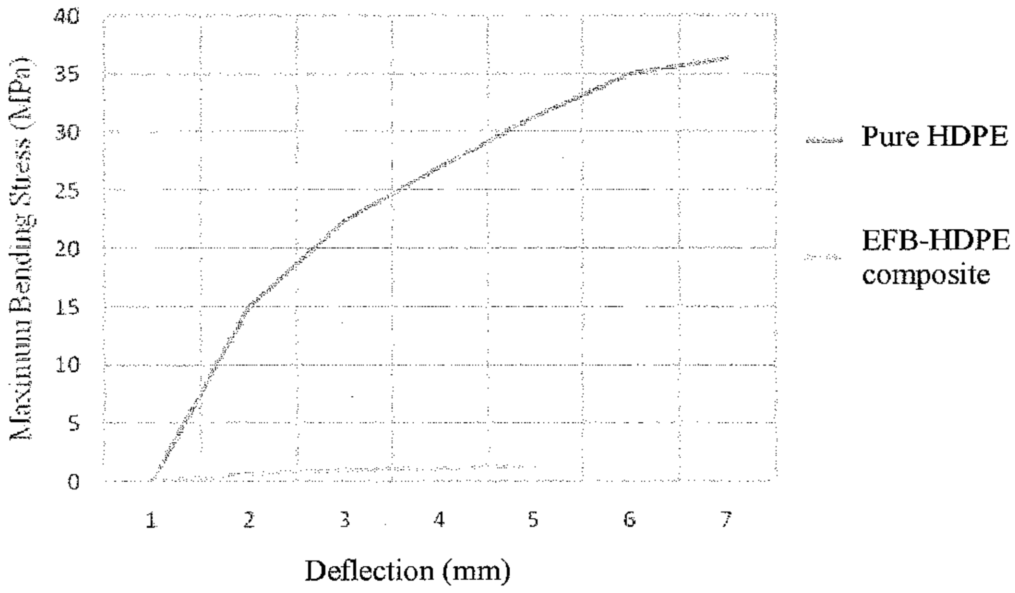


Figure 4.4: Typical stress-deflection curve of pure HDPE and EFB-HDPE composite prepared by compression molding process.

The maximum deflection of EFB-HDPE composite samples of injection molded was averagely same with pure HDPE that were prepared using the same process, as shown in Figure 4.5. Samples that were prepared using injection molding process were higher than that for the samples from compression molding process, as shown in Table 4.1. This proved that injection molded samples can withstand higher deflection compared to compression molded samples, without being affected by the presence of EFB fiber.

The EFB-HDPE composite sample of injection molding showed higher flexural modulus value of 638 MPa with standard deviation of 22 MPa compared to that of the compression molded, with a value of 446 MPa with standard deviation of 27 MPa, as shown in Table 4.1. The percentage difference between the two samples was 31%.

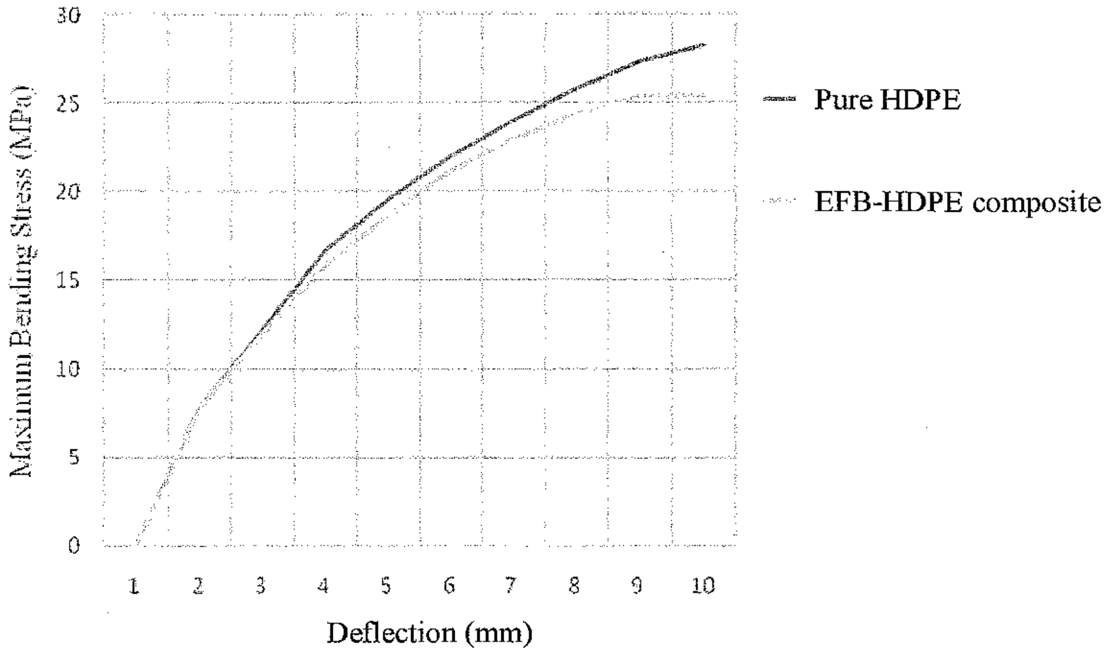


Figure 4.5: **Typical stress-deflection curve of EFB-HDPE composites and pure HDPE prepared by injection molding process.**

The high flexural modulus of EFB-HDPE composite samples obtained from injection molding process may be due to the EFB fiber properties which have better flexural properties. The EFB-HDPE composite samples and pure HDPE samples of compression molding, with the value of 446 MPa ± 27MPa and 480 MPa ± 32 MPa, respectively, showed small differences in the flexural modulus value. Pure HDPE that were prepared using injection molding and compression molding have percentage difference of 18%, with the value of 583 MPa ± 21 MPa and 489 MPa ± 32 MPa, respectively. This showed that different processing technique can affect the flexural modulus of pure HDPE more significantly compared to EFB-HDPE composite that were prepared using different processing technique.

The small differences in compression molded samples of both EFB-HDPE composite and pure HDPE were due to large pore space created within the samples. This phenomenon has taken a large impact on the value obtained for flexural modulus. The flexural test result indicates that compression molding leads to poor flexural properties as the process creates poor bonding between the EFB and HDPE. This may be the main reason for the low flexural properties of the compression molded samples.

Higher load can be applied on injection molded samples compared to that of the compression molded samples. The effect of the pores in the EFB-HDPE composite sample of compression molded sample causes the material to withstand only a small load of 30.9 N. Unlike the pure HDPE that were being prepared using compression molding, it can withstand higher tensile load of 41.7 N. Hence, in order to obtain mechanically improved composite, pore spaces that are created within the samples need to be reduced.

4.3 Summary

Pure HDPE prepared from injection molding have showed better tensile properties compared to other samples, as shown in Table 4.1. Less void and pores was identified to be the main reason of its high tensile properties. Materials with high number and volume of pores will lead to poor bonding and low mechanical properties. Samples from compression molding process have high number of pores compared to samples prepared by injection molding. Moreover, all samples prepared from compression molding process have lower tensile properties than that of samples from injection molded. In tensile test, the effect of EFB fiber is negligible.

However, the compression molding process does showed a higher value of tensile modulus of 269 MPa with a standard deviation of 5.8 MPa compared to that of EFB-HDPE composite sample prepared using injection molding, with a value of 240.9 MPa with standard deviation of 0.8 MPa. The different value of stress at yield for EFB-HDPE composite prepared using injection molding and compression molding were negligible.

For flexural properties, EFB-HDPE composite prepared using injection molding is higher than other samples prepared by using compression molding, as shown in Table 4.1. This may be due to the elastic property of the EFB fiber. Therefore, the effect of EFB fiber in flexural test is significant.

But, the EFB-HDPE composite showed the lowest flexural properties if it is prepared by using compression molding process. However, EFB-HDPE composite and pure HDPE prepared using compression molding showed high maximum deflection with the value of 6.7 mm and 5.9 mm, respectively.

Table 4.1: Mechanical Properties of EFB-HDPE composite and pure HDPE prepared using injection molding and compression molding process

Properties			EFB-HDPE composite		Pure HDPE	
			Injection Molded	Compression Molded	Injection Molded	Compression Molded
Tensile Properties	Tensile strength (MPa)	Mean[1]	18.3 ± 0.71	12.6 ± 2.0	22.1 [13]	18.8 ± 2.2
	Tensile modulus (MPa)	Mean[1]	240.9 ± 11.5	269 ± 5.8	1000 [13]	24.6 ± 0.8
	Stress at Yield (MPa)	Mean[1]	11.5 ± 0.4	10.9 ± 0.7	14.9 [13]	9.7 ± 0.9
Flexural Properties	Flexural Strength (MPa)	Mean[1]	33.7 ± 1.1	23.1 ± 2.2	29.2 ± 1.0	24.0 ± 1.6
	Flexural modulus (MPa)	Mean[1]	637.8 ± 21.9	446.1 ± 26.9	583.1 ± 20.9	479.6 ± 32.2
	Maximum Load (N)	Mean[1]	59.8 ± 3.2	30.9 ± 1.6	51.7 ± 2.0	41.7 ± 3.7
	Max. deflection (mm)	Mean[1]	9.0 ± 0.1	6.7 ± 0.1	9.0 ± 0.0	5.9 ± 0.2

[1] A mean calculated from at least 5 samples.

Chapter 5

Conclusions and Recommendation

5.1 Conclusions

The influence of processing techniques on mechanical properties of EFB-HDPE composite was examined. Results showed that the samples from compression molding process have lower tensile properties and flexural properties compared to that of the injection molded samples. The highest percentage difference of tensile strength was between EFB-HDPE composite from compression molding and pure HDPE prepared by injection molding of 43%. The lower tensile strength of the composites could be attributed to the void formation between the EFB fiber and HDPE matrix. The void may causes poor bonding between EFB fiber and HDPE matrix. Therefore, better mechanical properties of EFB-HDPE composite may be obtained if the pores that occurs in the material can be reduced. The presence of EFB fiber proved to improve the flexural strength and modulus of EFB-HDPE composites although it has a negative effect on the tensile properties.

As for the flexural strength, the highest percentage difference was between EFB-HDPE composite prepared by injection molding and compression molding with a value of 31.5%. This showed that in flexural test, EFB fiber does have a significant effect on the EFB-HDPE composite. Moreover the percentage difference for other flexural properties between EFB-HDPE composite prepared by injection molding and compression molding showed the highest value, such as flexural modulus with the value of 30%. Based on the tensile test and flexural test it is suggested that the EFB-HDPE composite product obtained from the injection molding process is preferable as the processing techniques showed high mechanical properties. It can be concluded that the processing technique can influence the mechanical properties of EFB-HDPE composites.

5.2 Recommendation

Further studies on combination of other natural fibers with polymer matrix may result in composites with better mechanical properties. For example, further studies can be done on mechanical properties of compounding fresh palm oil leaves with HDPE and the accompanied effects of various processing technique. Different result may be obtained from different types of natural fiber and polymer matrix that undergoes different processing technique. Reduction of pore spaces in the compression molding samples can be used as a case study to see the effect on mechanical properties of the EFB-HDPE composite material. This can be done by modifying the mold by introducing several holes on the top or at the side to allow any trapped air between the granulates.

Reference

1. Packaging Today. 5 August 2008, <http://www.packagingtoday.com/introplasticexplosion.htm>

2. W. D. (Rik) Brouwer. 5August 2008, <http://www.fao.org/DOCREP/004/Y1873E/y1873e0a.htm>

3. Wikipedia, *Injection Molding* 6 August 2008, <http://en.wikipedia.org/wiki/Injection_moulding#History>

4. CRC Press LLC. 9 August 2008 <http://composite.about.com/library/glossary/c/bldef-c1203.htm>

5. Goerg Hannes Michler, F. J., 2005, *Mechanical Properties of Polymers Based on Nanostructure and Morphology,* Taylor & Francis, London.

6. Muhamad Fatikul Arif 2008, *Investigation of Oil Palm Empty Fruit Bunch Composites Based on High Density Polyethlene Matrix*, Master Thesis, Universiti Teknologi Petronas, Perak, Malaysia.

7. Wanjun Liu , Lawrence T. Drzal , Amar K. Mohanty , Manjusri Misra, 2006, "Influence Of Processing Methods And Fiber Length On Physical Properties Of Kenaf Fiber Reinforced Soy Based Biocomposites", *Composites: Part B* 38: p.352-359.

8. A.C.N Singleton, C.A. Baillie, P.W.R. Beaumont, T. Peijs, 2002, "On the mechanical properties, deformation and fracture of a natural fiber/recycled polymer composites", *Composites: Part B* 34: p.519-526.

9. S. Panthapulakkal, A. Zereshkian, M. Sain, 2004, "Preparation and characterization of wheat straw fibers for reinforcing application in injection molded thermoplastic composites", *Bioresource Technology* 97 : p.265-272.

10. Kenneth G. Budinski, Micheal K. Bundinski, 2004, *Engineering Materials Properties And Selection. Eight Edition*, Pearson Prentice Hall, New Jersey.

11. Donald R. Askeland, Pradeep P. Phulé, 2003, *The Science and Engineering of Materials. Fourth Edition.* Brooks/Cole-Thomson Learning, Australia.

12. William D. Callister, 2007, *Materials Science And Engineering: An Introduction*, John Wiley & Sons, New York.

13. LyondellBasell Luponlen® 6031 M HDPE, Injection Molding Grade. 7 May 2009, <http://www.matweb.com>

Appendices

Table A-1: The tensile properties of pure HDPE prepared by compression molding process

	tensile properties			
	strength[1]	modulus[1]	stress at offset yield[1]	maximum load[2]
	18.9	24.8	10.0	914.7
	21.8	24.7	10.7	985.4
	16.6	23.3	9.8	952.6
	17.8	24.6	8.2	
		25.7	9.8	
Mean	18.8	24.6	9.7	950.9
STD[3]	2.2	0.8	0.9	35.4

[1] The units for strength, modulus and stress at offset yield are in MPa

[2] The units for maximum load are in N

[3] STD = Standard Deviation

Table A-2: The flexural properties of pure HDPE prepared by compression molding process

	flexural properties			
	strength[1]	modulus[1]	elastic strength[1]	maximum deflection[2]
	24.2	483.9	5.8	5.7
	24.6	491.6	4.8	6.2
	21.7	433.9	6.0	5.9
	25.5	509.0	5.7	5.8
				6.0
Mean	24.0	479.6	5.6	5.9
STD[3]	1.6	32.2	0.5	0.2

[1] The units for strength, modulus and elastic strength are in MPa

[2] The units for maximum deflection are in mm

[3] STD = Standard Deviation

Table A-3: The flexural properties of pure HDPE prepared by injection molding process

	flexural properties			
	strength[1]	modulus[1]	elastic strength[1]	maximum deflection[2]
	30.4	608.6	4.3	9.0
	28.2	563.7	4.4	9.1
	28.3	565.4	4.4	9.1
	28.2	563.7	4.2	9.0
	29.9	598.0		9.0
	30.0	599.0		9.0
				9.0
Mean	29.2	583.1	4.3	9.0
STD[3]	1.0	20.9	0.1	0.0

[1] The units for strength, modulus and elastic strength are in MPa

[2] The units for maximum deflection are in mm

[3] STD = Standard Deviation

Table A-4: The tensile properties of EFB-HDPE composite prepared by compression molding process

	tensile properties			
	strength[1]	modulus[1]	stress at offset yield[1]	maximum load[2]
	15.5	269.5	10.4	594.9
	11.5	270.9	10.3	560.0
	10.9	260.9	11.2	586.9
	12.6	274.6	11.7	
Mean	12.6	269.0	10.9	580.6
STD[3]	2.0	5.8	0.7	18.3

[1] The units for strength, modulus and stress at offset yield are in MPa

[2] The units for maximum load are in N

[3] STD = Standard Deviation

Table A-5: The flexural properties of EFB-HDPE composite prepared by compression molding process

	flexural properties			
	strength[1]	modulus[1]	elastic strength[1]	maximum deflection[2]
	22.7	454.8	0.2	6.6
	26.5	435.6	0.3	6.5
	21.8	415.5	0.3	6.8
	20.8	478.5	0.2	6.7
	23.9			
Mean	23.1	446.1	0.3	6.7
STD[3]	2.2	26.9	0.0	0.1

[1] The units for strength, modulus and elastic strength are in MPa

[2] The units for maximum deflection are in mm

[3] STD = Standard Deviation

Table A-6: The tensile properties of EFB-HDPE composite prepared by injection molding process

	tensile properties			
	strength[1]	modulus[1]	stress at offset yield[1]	maximum load[2]
	19.3	228.0	11.5	822.9
	18.0	236.5	11.9	776.5
	18.7	236.5	11.6	810.7
	18.4	253.5	11.0	797.8
	18.4	234.2		793.7
	17.0	256.7		738.5
	18.3			796.0
Mean	18.3	240.9	11.5	790.8
STD[3]	0.71	11.5	0.4	27.2

[1] The units for strength, modulus and stress at offset yield are in MPa

[2] The units for maximum load are in N

[3] STD = Standard Deviation

Table A-7: The flexural properties of EFB-HDPE composite prepared by injection molding process

	flexural properties			
	strength[1]	modulus[1]	elastic strength[1]	maximum deflection[2]
	31.8	636.7	9.3	9.2
	33.6	672.8	10.8	9.0
	34.7	695.0	14.7	9.1
	34.5	689.1	13.7	9.1
	33.1	661.6		9.0
	34.4	687.4		9.0
				9.0
Mean	33.7	637.8	12.1	9.0
STD[3]	1.1	21.9	2.5	0.1

[1] The units for strength, modulus and elastic strength are in MPa

[2] The units for maximum deflection are in mm

[3] STD = Standard Deviation

Planned Activity of the Project and Milestone of 1st Semester of Final Year Project

	Weeks														
Planned Activity	1	2	3	4	5	6	7		8	9	10	11	12	13	14
Literature review	▨	▨	▨	▨				**Mid-Semester Break**							
Submission of Preliminary Report				●											
Research of EFB Suppliers			▨	▨	▨										
Project Work				▨	▨	▨	▨								
Obtain EFB and HDPE				●											
Research of previous study				▨	▨	▨									
Material Extrusion									▨	▨					
Submission of Progress Report									●						
Seminar 2 (compulsory)									▨						
Injection molding											▨	▨			
Tensile and flexural testing												▨	▨	▨	
Data analysis														▨	▨
Submission of Interim Report															●
Oral Presentation															●

● Suggested Milestone

▨ Planned Duration

Planned Activity of the Project and Milestone of 2nd Semester of Final Year Project

	Weeks														
Planned Activity	1	2	3	4	5	6	7		8	9	10	11	12	13	14
Project Work Continue	▨	▨	▨					**Mid-Semester Break**							
Compression Molding				▨	▨	▨	▨		▨	▨					
Tensile Test and Mechanical Testing							▨		▨	▨	▨	▨			
Analysis Data							▨		▨	▨	▨	▨			
Submission of Progress report				●											
Project work Continue				▨	▨	▨	▨		▨	▨	▨	▨			
Analysis and Comparison									▨	▨	▨				
Finalize data and conclusion									▨	▨	▨	▨			
Submission Progress 2									●						
Seminar (Compulsory)									▨						
Poster Exhibition											●				
Submission of Dissertations (Softbound)														●	
Oral Presentation														●	
Submission of Project Dissertations (Hardbound)															●

● Suggested Milestone
▨ Planned Duration