EFFECT OF OIL PALM FIBER REINFORCEMENT ON MECHANICAL PROPERTIES OF POLYSTYRENE

by

HASNIZA ZAINAL

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Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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

(Assoc. Prof. Dr Faiz Ahmad)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
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.

(Hasniza binti Zainal)

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ABSTRACT

The effect on various mechanical properties of microstructures and physical properties of the polystyrene filled with different amount of oil palm empty fruit bunch fiber were investigated. The polystyrene reinforced with palm oil fiber composites observed the variation of the mechanical properties. For treatment of the fiber, NaOH and distilled water were used to ensure that the fibers were disaffected from dust and contamination. The fibers were dried and powders of EFBF were compounded with polystyrene in a co-rotating twin screw compounder. The composites feedstocks were injection molded by the specific molding temperature and pressure to produce the dog bone shape test sample. The test samples were tested with the tensile testing machine according to the ASTM standard to test the elasticity and modulus of the new composites. The microstructures composition were observed using the SEM and showed the different of microstructure characterization. Scanning electron microscope micrographs showed that the particles dispersed in the matrix. This project was identifying the percentage of volume fraction of reinforcement and polymer matrix was affecting the properties of the composites polymer.

TABLE OF CONTENTS

LIST OF TABLE

LIST OF FIGURE

CHAPTER 1: INTRODUCTION

1.1 Background

The plastic reinforces composites industries for application such as food packaging, transportation and construction have been established since early 1960s. The quick changes in research and development have led the material scientists and industries to expand the environmental friendly composite materials. As a result, natural fiber such as oil palm fiber, coconut coir and rice husk, are getting intention as reinforcement in polymer matrix. To the agro-based industry, this oil palm fiber have been utilize as boiler feedstock in the oil mill to recycle the waste of the fiber. In Malaysia the amount of Oil Palm Empty Fiber Bunch Fiber (OPEFBF) waste generated by the palm oil industries is very high, which is can be estimated approximately 8 million tons per year.

Composite materials owe their extraordinary uniqueness to the fibers which are used to reinforce the matrix. The combination of two very different phases, the matrix medium which is polystyrene and the empty fruit bunch fibers EFBF, allow a huge level of elasticity in the growth of microstructure arrangements. In addition, when fibers coupled with their polymer's mechanical strength and stiffness, it will let the natural structures to be better reinforced in areas of greater stress. One of the biggest new areas of research in this reinforced composite is in combining natural fibers with polymers. Although, prices for plastics have risen over the past few years, combination natural fiber to plastics provides a cost reduction to the plastic industry but in some cases, it wills increases performance as well. To ensure that the fiber can be utilized as reinforcement, an efficient study of the behavior of oil palm fibers will be investigate. [1-2]

1.2 Problem statement

Most of the reinforcing fibers such as glass and carbon are non-biodegradable and non-recyclable. Utilization of OPEFBF in packaging industry not only help solving environment problems related to the disposal oil palm fiber wastes, but also help packaging industry to produce environmental friendly biodegradable packaging materials. For this disadvantages that occur for the current use of polystyrene, this project will be improve the properties in term of the mechanical properties of tensile strength and modulus of elasticity of the polystyrene when reinforced with fiber. Thus, it can be modified at the composite properties between the natural fibers and the polymer matrix which lead to the weakening the composites. In other hand, this paper will be study the percentage of natural fiber which is the Oil Palm Fiber and Polystyrene can be cooperate to produce the composites, which known as a biodegradable product. [3]

From the study and researches, there are various disadvantages when using the polystyrene as main composites for their applications. There are:

- Poor solvent resistance.
- Subject to environmental stress cracking.
- Not suitable for microwave applications.
- Not suitable for freezer applications.
- Poor barrier properties.

1.3 Objectives

- To investigate the potential of Oil Palm Empty Fruit Bunch Fiber as a reinforcement for the polystyrene.
- The purpose of this project is to study the effect of percentage in volume fraction between oil palm fibre reinforcement and Polystyrene.
- To study the effect on mechanical properties of tensile strength, modulus of elasticity and also the microstructure of the composites.

1.4 Scope of Study

This project is covering the study in agro based fibers which is using the empty fruit bunch fiber (EFBF) of the palm oil. It also includes the studies of the performance of the palm oil and their exploitation as a fiber in polymer composites. The fiber and Polymer will be compounded by using the extruder machine to produce new composites with respect to the percentage of rule of mixture. The new composite will be testing with injection molding consecutively to test with the tensile testing to investigate the behaviour of the composites. The influence of the reinforcement into the performance of the composites is also determined by the mechanical properties of the tensile strength and tensile modulus. [3]

CHAPTER 2: LITERATURE REVIEW

2.1 Composite Materials

Composite materials for construction, engineering, and other related applications are produced by combine two or more materials in such a way that the elements of the composite materials are not fully blended. Composite materials take improvement of the special strengths and capacities of different materials that use as the reinforcement. In the case of palm oil fibers and rice husks, they use the natural waste as material to reinforce with the polymer. Typically, reinforcing materials are strong with low densities while the matrix is usually a ductile, or tough, material. If the composite is designed and fabricated correctly, it combines the strength of the reinforcement with the toughness of the matrix to achieve a combination of desirable properties not available in any single conventional material. Now a day, there have been investigating the composite materials to build stronger and lighter objects for industries application.

The common of composite materials use two elements which is a matrix and reinforcement. The reinforcement material is should be stronger and stiffer to form a kind of backbone, while the matrix will keeps the reinforcement in a position. The matrix also protects the reinforcement, which may be brittle or ductile. Generally, composite materials have excellent compressibility combined with good tensile strength, making them flexible in a wide range of situations. The common composite materials can be classified as follows: [4]

1. Fibers as the reinforcement (Fibrous Composites)
2. Particles as the reinforcement (Particulate composites)
3. Flat flakes as the reinforcement (Flake composites)
4. Fillers as the reinforcement (Filler composites)

2.2 Fibers as the reinforcement (Fibrous Composites)

Composite plastics is classifies to the types of plastics that result from bonding two or more homogeneous materials with different material properties to obtain a final product with certain desired material and mechanical properties. Fiber reinforced plastics are a category of composite plastics that specifically use fibrous materials to mechanically enhance the strength and elasticity of plastics. The original plastic material without fiber reinforcement is known as the matrix. The matrix is a tough but relatively weak plastic that is reinforced by stronger stiffer reinforcing filaments or fibers. The extent that strength and elasticity are enhanced in a fiber reinforced plastic depends on the mechanical properties of the fiber and matrix, their volume relative to one another, and the fiber length and orientation within the matrix. Reinforcement of the matrix occurs by definition when the Fiber Reinforcement material exhibits increased strength or elasticity relative to the strength and elasticity of the matrix alone. [4]

2.3 EFBF as Reinforcement

Palm fiber is natural fiber extracted from palm oil bundles in the empty fruit bunch. During the manufacturing process of palm fiber, EFB are shredded, separated, refined and dried. The manufacturing process does not involved chemical process or exposure. Table 1 below shows the characteristic of palm oil fiber. [5]

Table 1: Characteristics of oil palm empty fruit bunch fiber [5]

Lignin content (%)	Cellulose content (%)	Density (g/cc)	Average Diam. (µm)	Ash content (%)
19	65	0.7–1.55	150–500	2

2.4 Polystyrene as Matrix

Polystyrene is an aromatic polymer made from the aromatic monomer styrene, a liquid hydrocarbon that is commercially manufactured from petroleum by the chemical industry. Polystyrene is one of the most widely used kinds of plastic. Polystyrene is a thermoplastic substance, normally existing in solid state at room temperature, but melting if heated for molding or extrusion, and becoming solid again when cooling off. Pure solid polystyrene is a colorless, hard plastic with limited flexibility.

This information used to determine the temperature for the compounding and injection molding process. With the melting temperature of the PS, we can adjust the temperature so the defect during the process can be reduce to ensure the quality of the composite that will be produce is excellent. Table 2 shows the properties of polystyrene; which is can evaluate the result from the tensile test between pure polymer and polymer reinforced to study the changes in mechanical properties of the reinforced material. [6]

Table 2 : Properties of the Polystyrene [6]

Properties	
Density	1050 kg/m³
Density of EPS	25-200 kg/m³
Young's modulus (*E*)	3000-3600 MPa
Tensile strength (s_t)	46–60 MPa
Elongation at break	3–4%
Melting point	240 °C

2.5 Fiber Length

The effectiveness of the fiber reinforcement is depend on several factor including the type of resin used, the quantity of fiber in resin matrix, length of fibers, form of fibers, direction of fiber adhesion of fiber to polymer matrix and impregnation of fibers with resin. Load transfer from matrix to the fiber with short fibers composites and fiber adhesions. The critical fiber length is known as the shortest effective fiber length.

2.6 Fiber Volume Fraction

The fiber volume of a composite material may be determined by chemical matrix absorption, which is the matrix is dissolved and the fibers weighed and calculated from substituent weights and densities technique may be used and the volume fraction determined as the area fraction of each constituent. It has been described by increasing the fiber content the tensile strength increases linearly according to the law of mixtures. It is preferable to define the fiber quantity in the polymer matrix in volume percentage rather than weight percentage. [7]

2.7 Fiber Orientation

It is known when the directional orientation of the fiber is with their long axis and perpendicular to an applied force the result is a high reinforcing effect. However, forces that are perpendicular to the long axis of the fibers produce matrix-dominated failures and, consequently, result in low reinforcing efficiency. Multi-directional fiber reinforcement has been employed to minimize the anisotropic behavior of unidirectional fiber reinforcement. On the other hand, multidirectional fiber reinforcement is accompanied by a decrease in strength when compared with unidirectional fibers. [8]

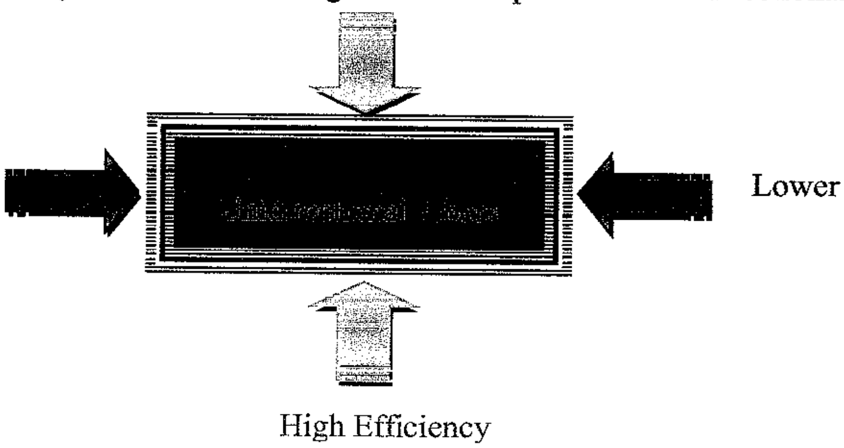


Figure 1: Reinforcing efficiency of unidirectional fibers is direction dependent (anisotropic) [8]

Composites that have randomly-oriented fibers are isotropic in their mechanical and physical properties. In other words, the strength of the fiber-reinforced composite (FRC) is not related to the direction of the stress. It can be supposed the two fiber systems could be used in different clinical applications, where different properties are required.

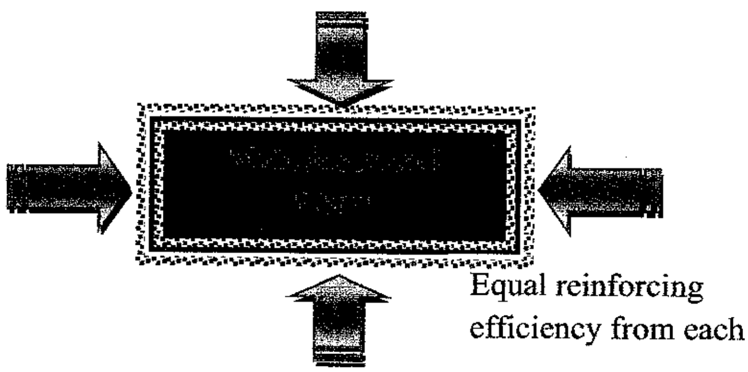


Figure 2: Reinforcing efficiency of multidirectional fibers is not direction dependent (isotropic) [8]

2.8 Determination of Rule of Mixture

In the fiber reinforced material the fibers are distributed throughout the matrix in a pattern that can be describe as repeating. [9]

$$M_c = M_f + M_m \quad (1)$$

$$V_f = \frac{M_f}{\rho_m} \quad (2)$$

$$V_m = \frac{M_m}{\rho_m} \quad (3)$$

$$V_c = V_f + V_m \quad (4)$$

$$v_f = \frac{V_f}{V_c} \quad (5)$$

Where

$M_c = Mass\ of\ composite\ specimen, (g)$

$M_f = Mass\ of\ EFBF, (g)$

$M_m = Mass\ of\ matrix, (g)$

$\rho_f = Density\ of\ EFBF, (g/cm^3)$

$\rho_m = Density\ of\ matrix, (g/cm^3)$

$V_c = Volume\ of\ composite\ specimen, (cm^3)$

$V_f = Volume\ of\ EFBF, (cm^3)$

$V_m = Volume\ of\ matrix, (cm^3)$

$v_f = Composite\ volume\ fraction$

2.9 Stress strain curve

The tensile modulus is the ratio of stress to elastic strain in tension. A high tensile modulus means that the material is rigid - more stress is required to produce a given amount of strain. In polymers, the tensile modulus can be close or may vary widely. This variation may be 50% or more, depending on resin type, reinforcing agents, and processing methods. The stress ***u*** in the material increases but, because of the decrease in the cross-sectional area ***A***, the stress ***S*** calculated from the load and the original cross-sectional area ***A***, increases more slowly, attains a maximum value S, and usually declines before the specimen breaks. Refer figure 7 for the detail of the tensile modulus using the stress strain curve. [10]

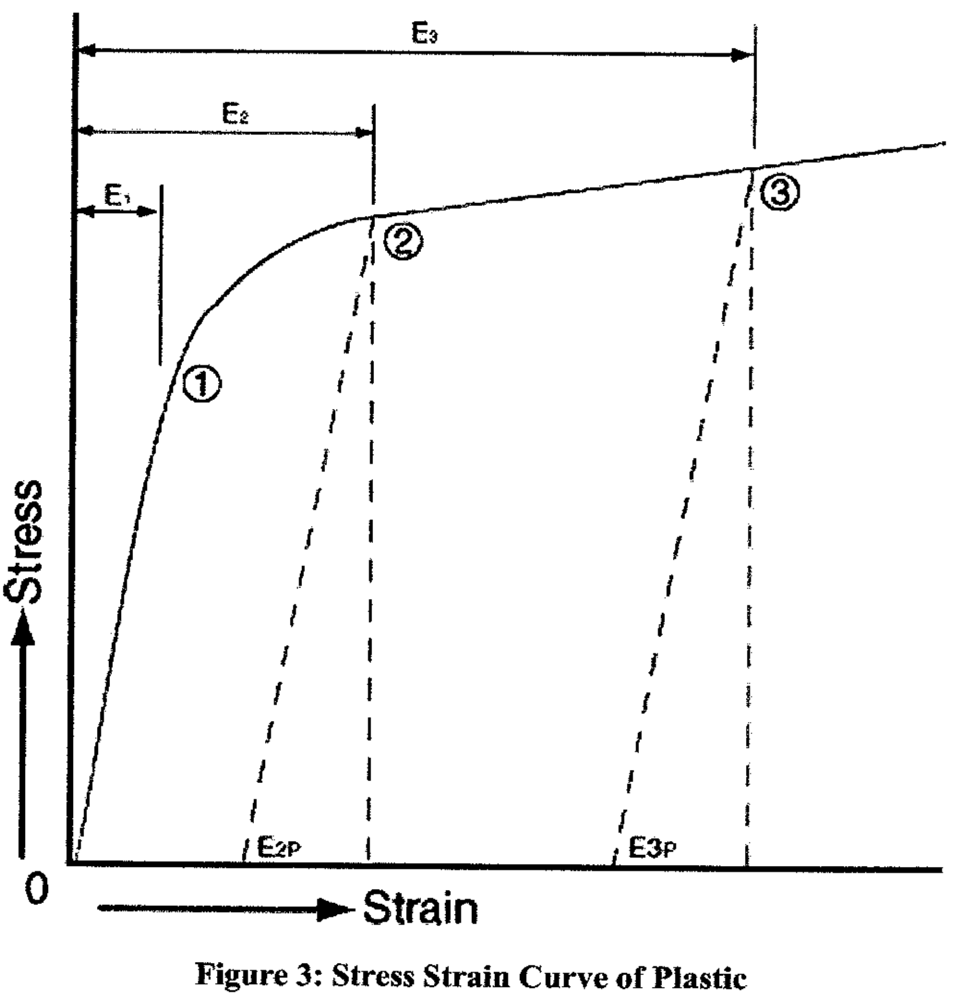


Figure 3: Stress Strain Curve of Plastic

2.10 Properties obtained from the tensile test

2.9.1 Yield strength

When the stress was applied to the material, the material inhibits elastic deformation. The strain that develops is completely recovered when the applied stress is release. However, if the stress is continued to apply, the material tend to exhibit both elastic and plastic deformation. The critical stress value is needed to initiate plastic deformation is defined as the elastic limit of the material. [10]

2.9.2 Stiffness

A qualitative measure of the elastic deformation produces in a material. A stiff material has a high modulus of elasticity. The stiffness, *k*, of a material is defined by: [10]

$$k = \frac{P}{\delta} \qquad (6)$$

Where:

P is the applied force

δ is the deflected distance

As both the applied force and deflection are vectors (respectively ***P*** and **δ**), in general their relationship is characterized by a stiffness matrix, ***k***, where:

$$\boldsymbol{P} = \boldsymbol{k}\boldsymbol{\delta} \qquad (7)$$

The deflections in general, refer to a point distinct from that where the force is applied and a complicated structure will not deflect purely in the same direction as an applied force. The stiffness matrix enables such systems to be characterized in straightforward terms.

2.11 Relationship to elasticity (Modulus of Elasticity)

In general, elastic modulus is not the same as stiffness. Elastic modulus is a property of the constituent material where stiffness is a property of a solid body. That is the modulus is an intensive property of the material, stiffness, which is an extensive property of the solid body dependent on the material and the shape and boundary conditions. [10]

$$k = \frac{AE}{L} \qquad (8)$$

Where:

A is the cross-sectional area,

E is the Young's modulus,

L is the length of the element.

CHAPTER 3: METHODOLOGY

3.1 Research Methodology

3.1.1 (EFBF) Preparation

Oil palm empty fruit bunch (OPEFB) fibers have been collected from local palm oil factory which is from Kilang Kelapa Sawit Lekir Sdn. Bhd. The fiber will be washed thoroughly with 2.0% alkaline to remove the adhered and contaminants. The fibers have been oven dried for one day for 100°C to remove moisture trapped in the fiber. After that the fiber have been granulate by using the granulator to make the fiber as powder. Below is the flow chart that shown the procedure that will be using to prepare the fiber.

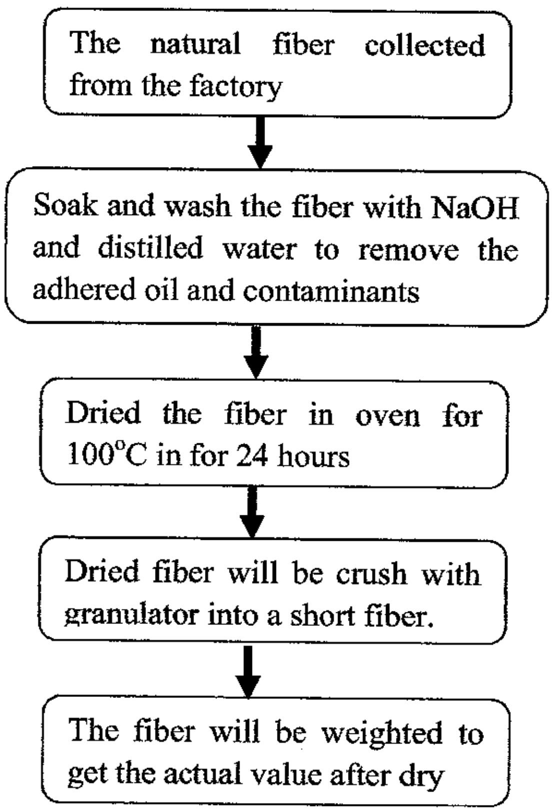


Figure 4: Flow diagram of the preparation of the Fibers

3.1.2 Flow of the process

Figure 5 shows the flow of the process from treatment of the fiber until mechanical testing of the reinforced composite.

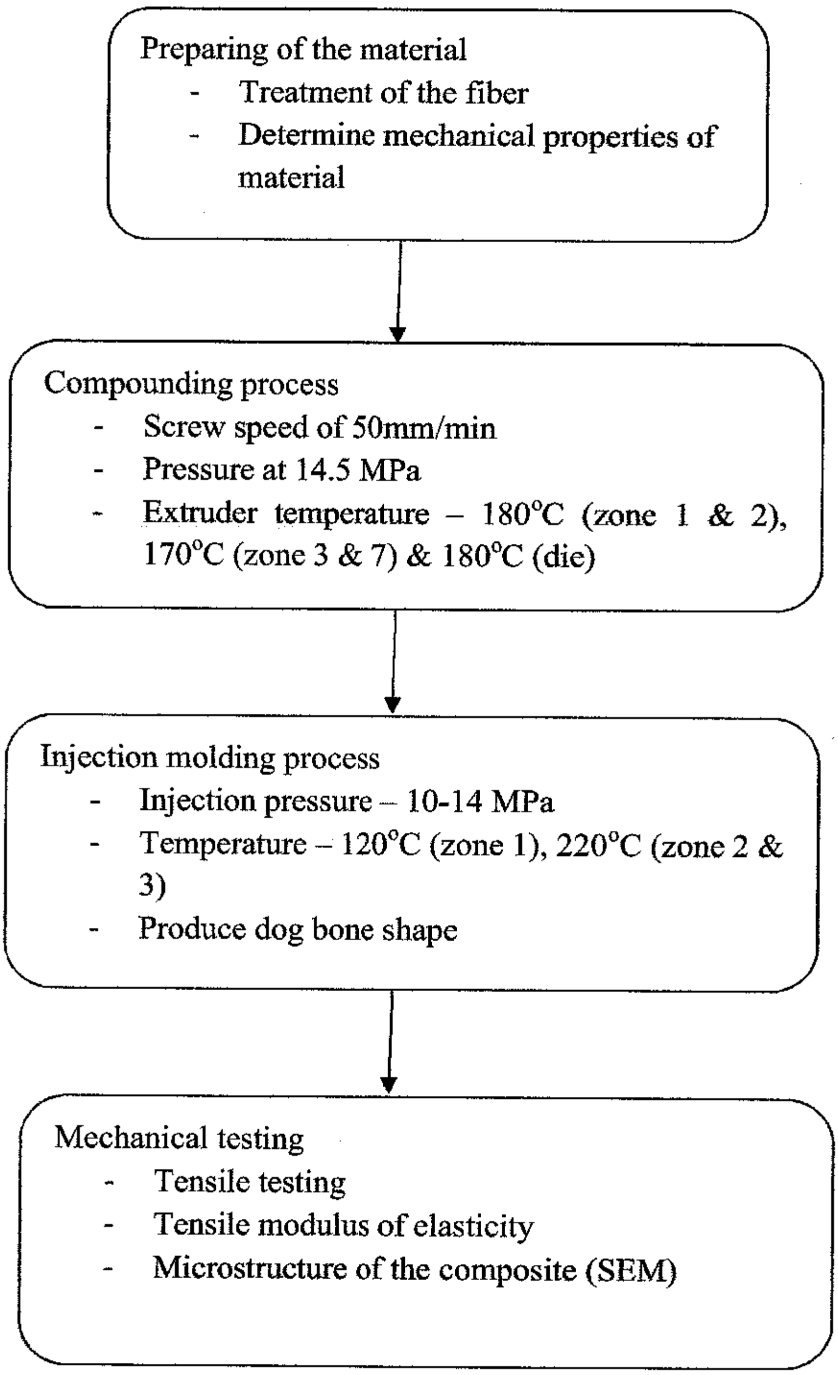


Figure 5: Flow diagram of process of making the composites and the testing

3.1.3 Fiber Volume Fraction

Based on the formula that given before, the volume fraction of the polystyrene and fiber have been determine in order to verify the mass of polystyrene and fiber that will be using for the compounding and injection molding. Table 3 below shows the volume fraction for the fiber and polystyrene.

Basis weight of the composites we assume about **500 g** the theoretical value for the weight that ideal for the compounding and injection molding process.

Density of the EFBF: $1.15 g/cm^3$

Density of the PS: $1.05 g/cm^3$

Table 3: List of the % of Volume Fraction.

No of exp	% of the fiber	% of the PS	Vol of fiber (cm^3)	Vol of PS (cm^3)
1	0	100	0	476.19
2	5	95	21.74	452.38
3	10	90	43.48	428.57
4	15	85	65.22	404.76
5	20	80	86.96	380.95

3.1.4 Fiber Weight Fraction

Base from the Fiber Volume Fraction, the amount that will be used can be determined by using the weight fraction. This weight will be use to find the exact amount for each percentage of fiber and Polystyrene. From the equation shown below, the weight can be calculated.

$$weight_{fiber} = vol_{fiber} \times \rho_{fiber}$$

$$weight_{PS} = vol_{PS} \times \rho_{PS}$$

Table 4 : List of the % of Weight Fraction.

No of exp	% of the fiber	% of the PS	Wt of fiber (g)	Wt of PS (g)
1	0	100	0	500
2	5	95	25	475
3	10	90	50	450
4	15	85	75	425
5	20	80	100	400

3.1.5 Compounding

A dry blends of polystyrene and EFBF is fed to the extruder for mixing. The strand-coating method consists of passing the roving or tows of fibers through extruder to coated and impregnated by the molten polystyrene. The impregnated fiber tow is cooled in a water bath and then chops into required length. Figure below show the Extruder Machine that will be use for the compounding process of the EFBF and Polystyrene. The percentage of volume fraction is need to precise since the fiber especially will be degraded and burn during the compound process.

Figure 6 : Composites after compound

3.1.6 Properties of Extruder and Injection Molding

Table 5: Properties of Extruder Machine

Barrel	Temp (^{o}C)
1	190
2	190
3	190
4	190
5	190
6	190
7	200
Flange	210
Die	220

Screw Speed	50 Rpm
Pressure	14.5 MPa

Table 6: Properties of Injection Molding Machine

Temperature 1 (^{o}C)	120
Temperature 2 (^{o}C)	220
Temperature 3 (^{o}C)	220
Pressure	100-140 bar
Screw Pos	34.6mm
Cycle time	30.00 s

3.1.7 Injection Molding

All the compounds that produced by the extruder machine were transferred to the injection molding machine. The compound is fed to the machine through the hopper. The compound enter the injection barrel by gravity though the feed throat. Upon entrance into the barrel, the resin is heated to the appropriate melting temperature. The resin is injected into the mold by a reciprocating screw. Therefore, the temperature for the injection molding can be reduce since the melting temperature of the fiber is low compare to the polystyrene. This process is to avoid burning during the injection molding process. For this type of testing, it produces the dog-bone shape specimens for following mechanical testing. [11].

Figure 7: Injection Molding Machine

3.2 Mechanical Testing

3.2.1 Tensile Testing

A standard test piece is gripped at either end by suitable apparatus in a testing machine which slowly exerts an axial pull so that the steel is stretched until it breaks. Tensile tests provide different measures of the material's mechanical properties. The tensile test gives a measure of the Young's modulus of the material as well as the tensile strength and yield point. The load required for the flex test is usually much lower which less than 2000N. Injection molded test samples were provided for this experiment. In order to give accurate results, the tensile samples should not have notches or burrs on their edges and should be free of scratches. Test was performed until tensile failure occurred. Figure below show the tensile test machine that will be used to test the strength of the composite that have be produce in dog bone shape by injection molding process. [12]

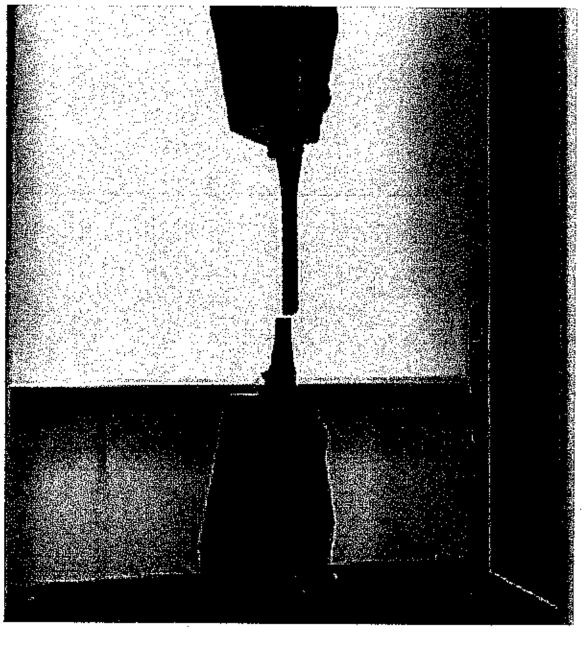


Figure 8: Tensile Test Machine

3.3 Microstructure Fracture of the Composites

Figure below is the SEM machine. The **scanning electron microscope (SEM)** is a type of electron microscope that examines the images of sample surface by scanning it with a high-energy beam of electrons. The electrons interact with the atoms that make up the sample producing signals that contain information about the sample's surface topography, composition and other properties such as electrical conductivity. The SEM has a large depth of field, which allows a large amount of the sample to be in focus at one time. The SEM also produces images of high resolution, which means that closely spaced features can be examined at a high magnification. Preparation of the samples is quite easy since most SEMs only require the sample to be conductive. When a tensile stress is applied along the fibers, it deforms in a brittle manner, with void formation and eventually produces a dimple fracture surface. Fracturing will be happen if the bonding between the fiber and matrix is poor. Void can form between the fiber and the matrix and cause the pull-out. [12]

Figure 9: Scanning Electromagnetic Microscopic

CHAPTER 4: RESULT AND DISCUSSION

4.1 Mechanical Properties of Tensile Testing

Table 7 : Tensile Testing Properties

Properties of the Tensile Test					
% of fiber	Stiffness (kN/m)	Young Modulus (MPa)	Tensile Strength (MPa)	Load at Maximum (N)	Extension at Maximum (mm)
0%	535	1072.8	32.52	1301.2	6.015
5%	379	768.0	22.20	887.79	3.8508
10%	532	1077.3	25.35	1014.0	3.7168
15%	580	1174.0	24.42	976.73	3.0471
20%	231	467.6	19.92	796.65	5.3107

From table 7, it shows the summary of the mechanical properties that obtained from the tensile testing, the comparison between the 100% of Polystyrene and reinforced composite materials can be classified by plotting the graphs.

4.2 Graph of the tensile properties vs. percentage of fiber

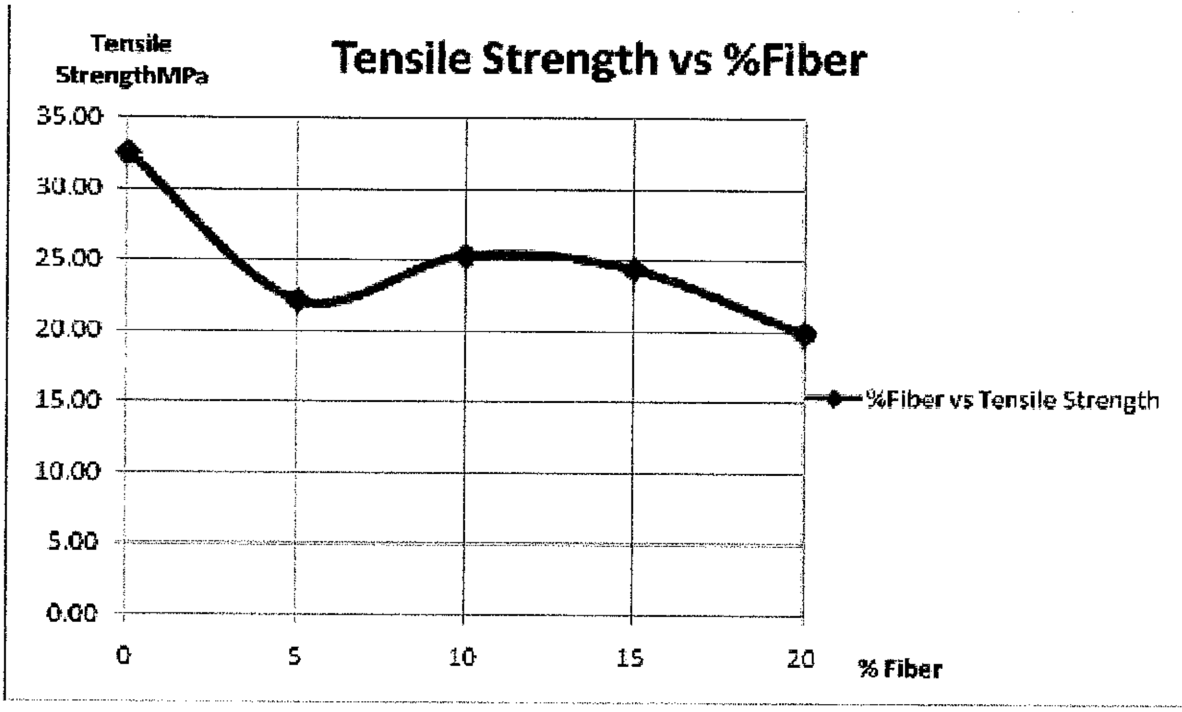


Figure 10: Graph of Tensile Strength vs. % Fiber

Fiber-reinforced composites revealed declining elongation at break values with fiber content increasing. An approximately 80– 90% reduction was recorded at 15% fiber content compared to the pure polystyrene (Fig. 14). Stiffness or modulus was found to increase consistently with fiber content (Fig. 15). The modulus of a short fiber composite depends on several factors, including fiber length, fiber orientation, fiber and matrix volume fractions, as well as modulus of both components.

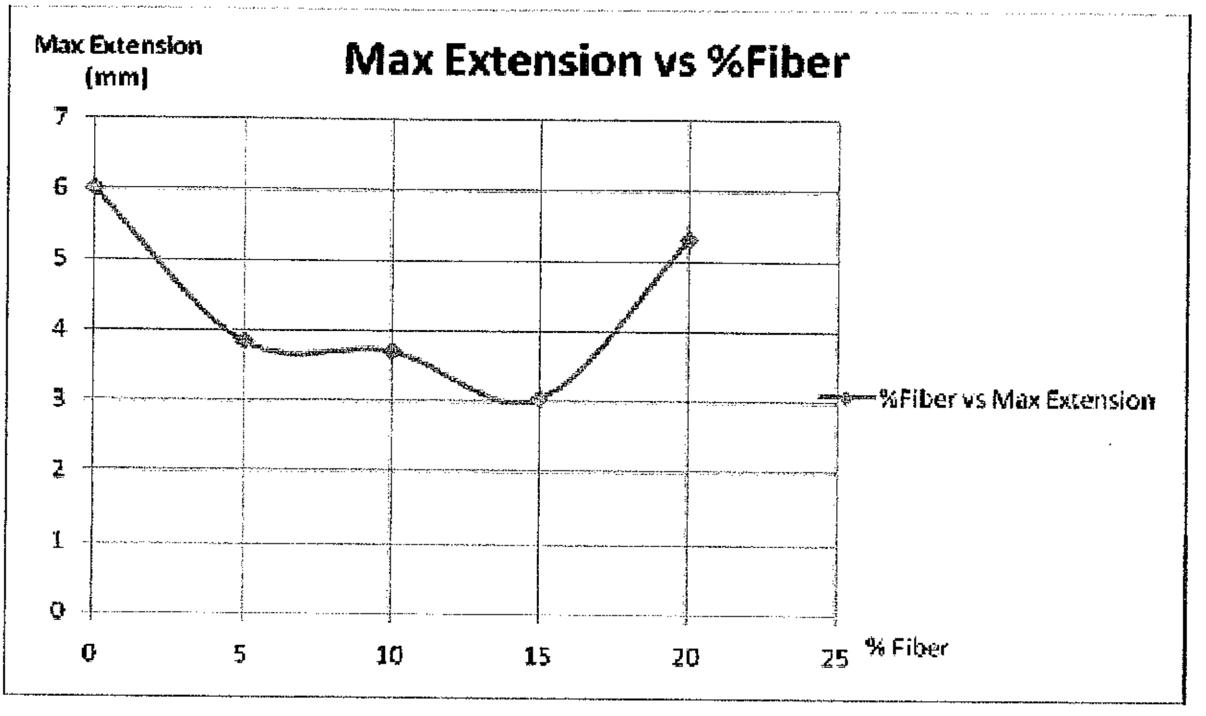


Figure 11: Max Extension vs. %Fiber

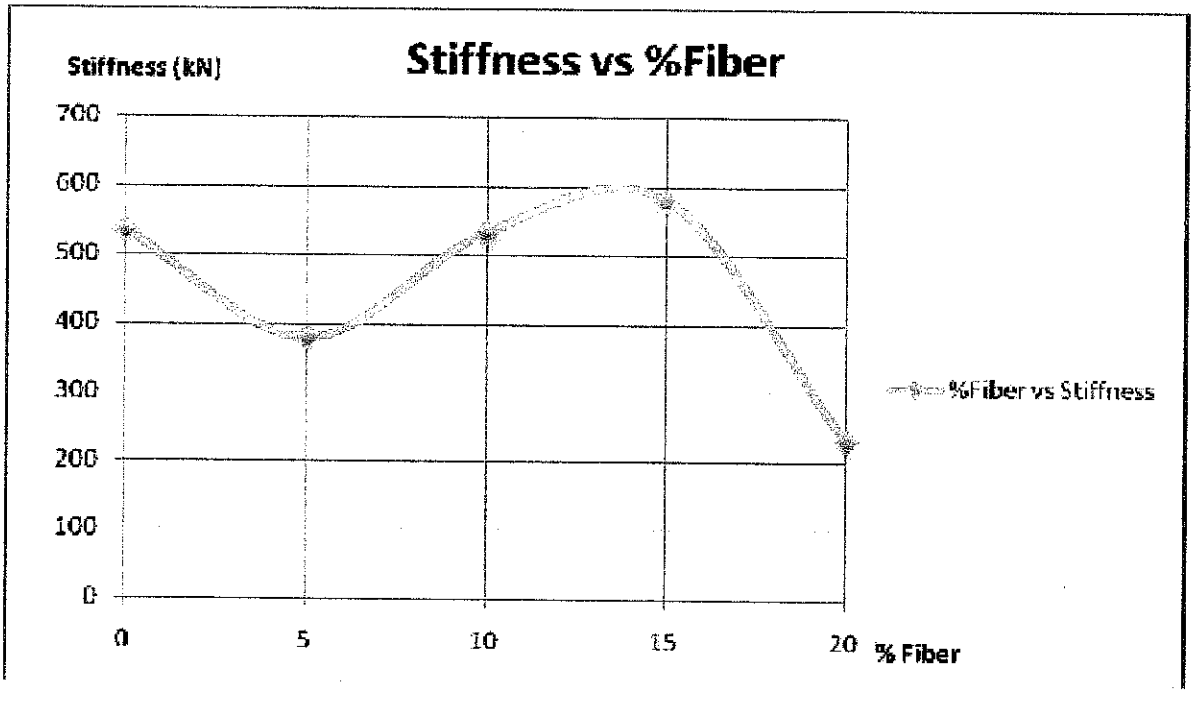


Figure 12: Graph of Stiffness vs. % Fiber

Reinforced materials with higher Fiber Volume Fractions (FVF) in a composites material were having large gaps between the fiber bunches. Fiber diameter is an important factor here with the smaller diameter fibers were provide higher fiber surface areas, spreading the fiber and matrix interfacial loads. As a general rule, the stiffness and strength of a composite material will increase in proportion to the amount of fiber present. However, at 20% FVF which is depend on the technique the fibers pack together although tensile stiffness may continue to increase, the composite material's strength will reach a peak and then begin to decrease due to the lack of sufficient resin to hold the fibers together properly.

4.3 SEM morphological study

Figures (13-14) show SEM micrograph of the tensile test surfaces in the Polystyrene. There is a clear evidence of brittle failure in the 100% of Polystyrene sample. In this sample, only the brittle facture can be identify since there is no interactions between polymer and fiber yet.

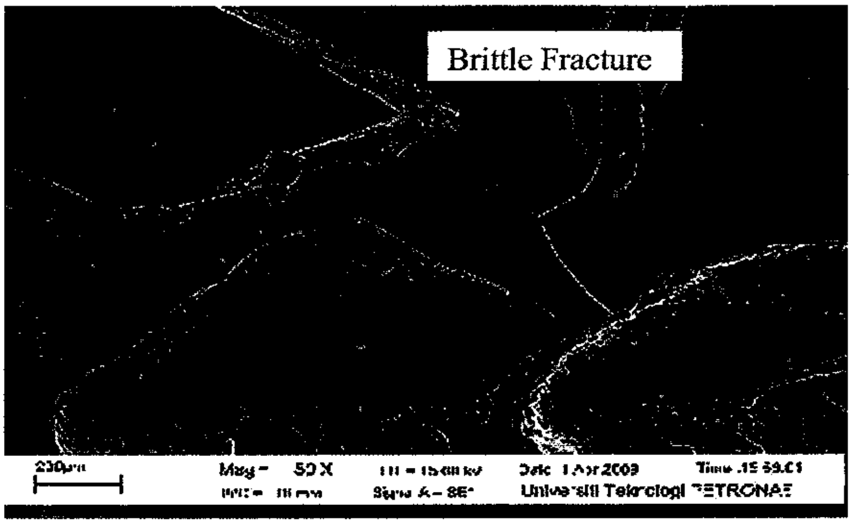


Figure 13: SEM micrograph shows tensile test surface of 100% of Polystyrene

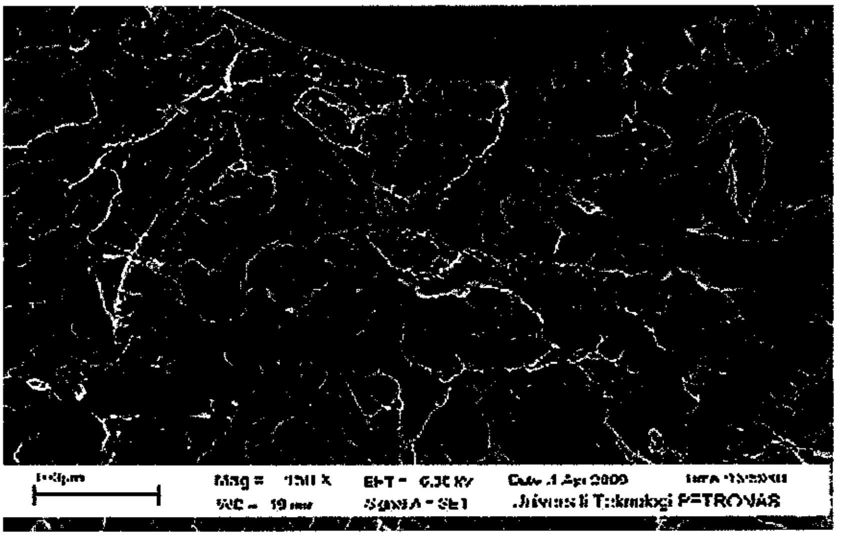


Figure 14: SEM micrograph shows brittle surface of 100% of Polystyrene

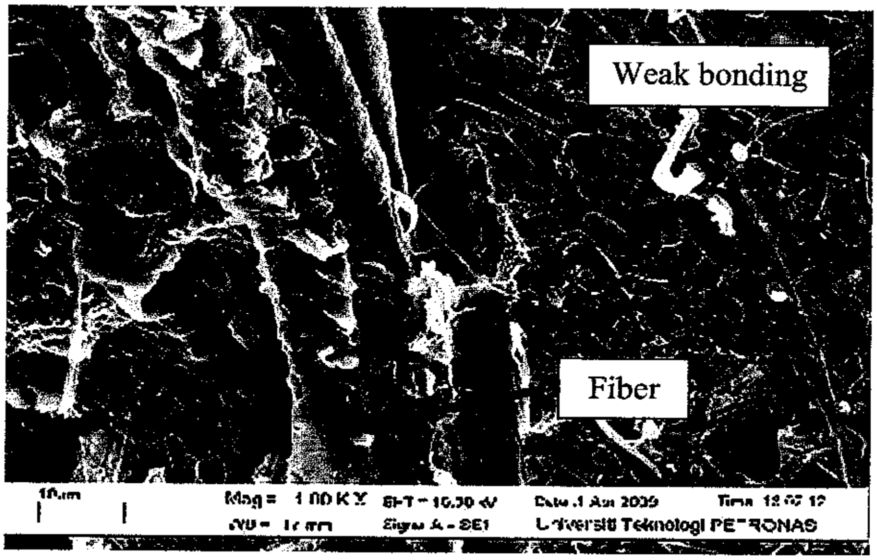


Figure 15: SEM micrograph shows weak bonding in 5% fiber composites

There clear fracture surface shows poor fiber or matrix interfacial bonding between the fibers and PS matrix. The weak bonding between the fiber and polymer cause by the improper preparation of the material and also not using the proper coupling agent to bond the material. In figure 18 shows the length of the fiber, **925.1μ** which is can be categorize as long fiber and the diameter of the fiber is **106.2μ.** In other words, as expected for good fracture mechanics results, the interfacial toughness was independent of both fiber length and fiber diameter.

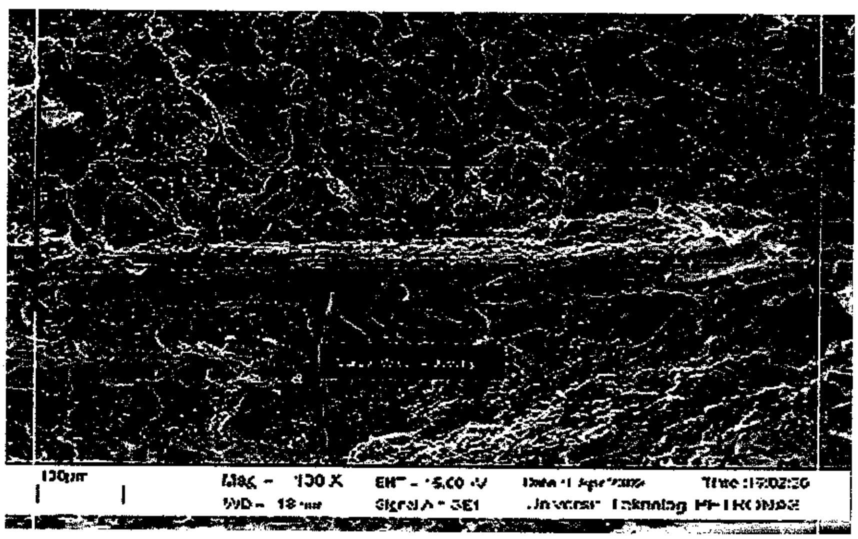


Figure 16: SEM micrograph shows fiber length in 5% fiber composites

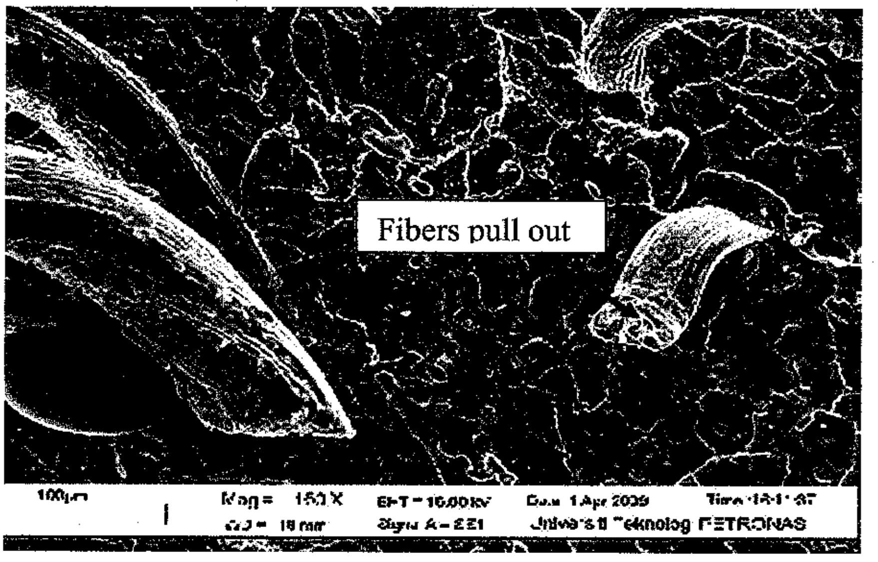


Figure 17 : SEM micrograph shows fiber pull out in 10% fiber composites

According to the SEM fractographs (Fig. 17-18), fiber pull-out and debonding predominate in fracture surfaces with fairly clean and recognizable fiber surface without matrix adherence. Crack propagation in fiber reinforced composites is run by link stresses provided by fibers along the crack. The behavior of fiber reinforced structural components under general loading conditions which are where mixed mode crack propagation is possible and the normal and shear stresses acting on a crack are a function of crack opening and shearing displacements.

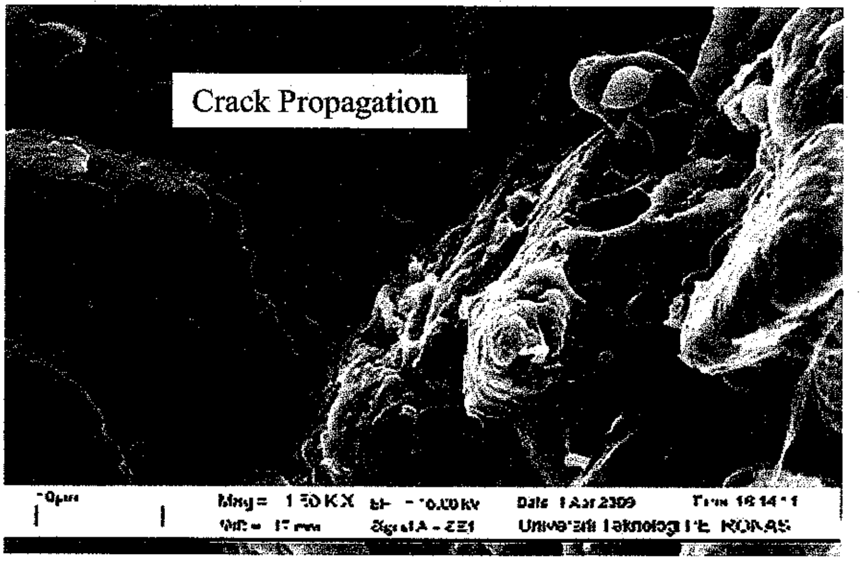


Figure 18: SEM micrograph shows crack propagation in 10% fiber composites

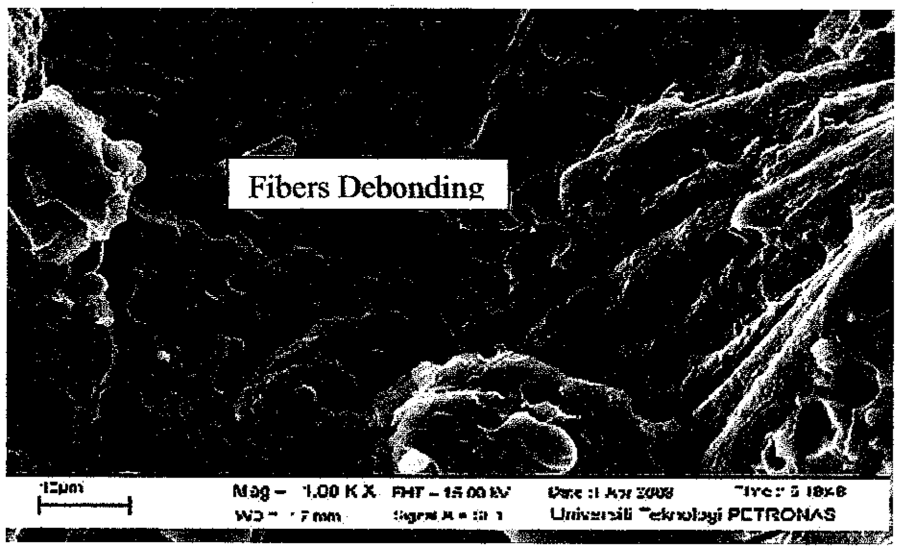


Figure 19 : SEM micrograph shows fiber debonding in 15% fiber composites

From figure 22 and 23, the interfacial debonding between fibers and the matrix may occur under increasing deformations and influence the overall stress-strain behavior of composite materials. After the interfacial debonding, the debonded fibers may lose the load-carrying capacity in the debonded direction (Zhao and Weng 1996, 1997). Yet, they are still able to transmit internal stresses into the matrix through the bonded portion and are regarded as partially debonded fibers (Zhao and Weng 1996, 1997). It can be assumed that the debonding of fibers is controlled by the stress of the fibers and the statistical behavior of the fiber-matrix interfacial strength. [13]

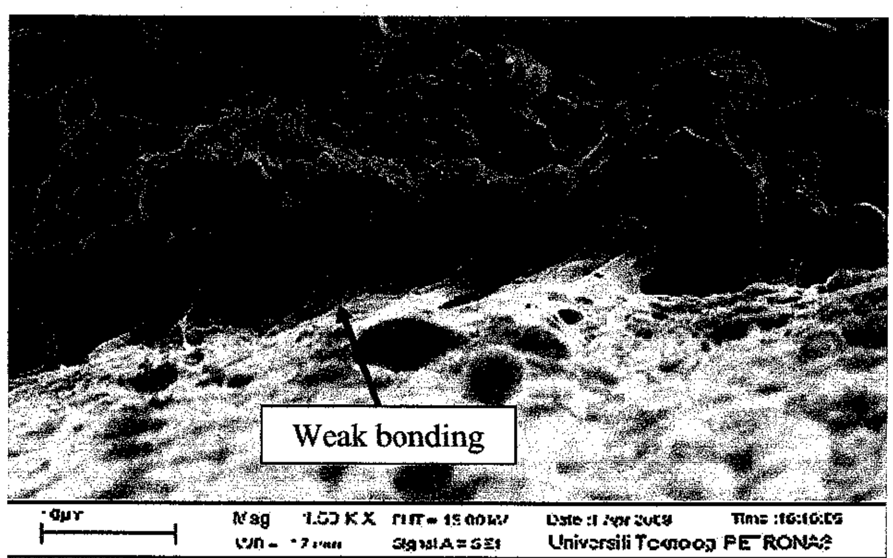


Figure 20: SEM micrograph shows weak bonding in 15% fiber composites

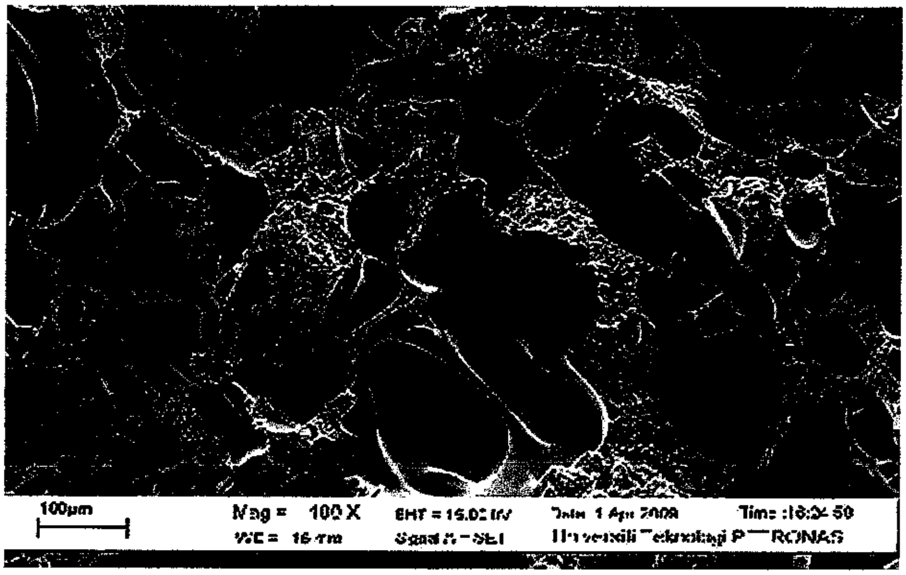


Figure 21 : SEM micrograph shows bubbles in 20% fiber composites

From SEM micrograph, the samples show voids and bubbles which are one of the failures that could be occurring during the manufacturing process. From figure (21&22) it shows a lot of bubble at the tensile test surface. For the percentage fiber of 20%, we can see that the contact of fiber and matrix are weak since the fiber burn during the compounding. The composite become more brittle and burn during the injection molding process.

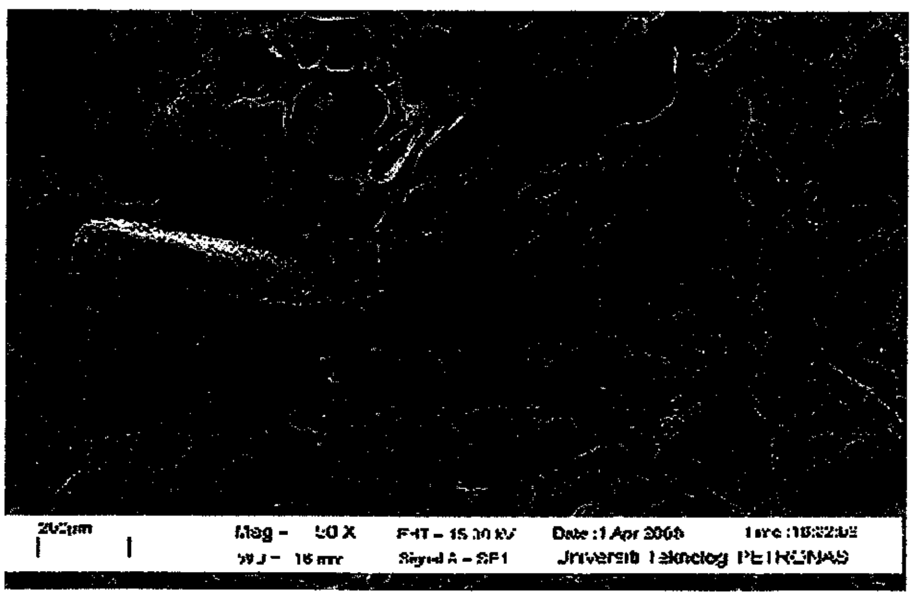


Figure 22: SEM micrograph of 20% fiber composites

CHAPTER 5: CONCLUSION

This study of the palm oil fiber as reinforcement to the polystyrene is potentially to enhance the capability of the polymer composites. The mechanical properties of the composites may be further enhanced by using suitable bonding agents and proper method to make it accomplish and improve the bonding between the palm oil fiber with and polymer matrix. The particle size and distribution strongly affects the damage mechanisms of the composite due to increased stress levels in the matrix between the particles in the matrix between the particles. From the result shown that when the fiber volume fraction increase by 5%, the tensile strength of the reinforced composites is decreasing due to the quantity of the fiber added into the polymer. It is led to the weak bonding between the fiber and matrix. The modulus and the stiffness of the composites show the increasing when the fiber volume fraction is increase from 10% to 15% of fiber. Then the properties of composite show the declining at 20% of fiber. The interfacial bonding of the composites shows the weak bonding between fiber and matrix due to the improper preparation of the material. As conclusions, this project shows the successful study of the effect of fiber volume fraction to the mechanical properties of the composites materials. It shows the dissimilarity between the tensile strength, modulus of elasticity and stiffness of the composite when the volume fraction increase by 5%. But, when the fiber volume fraction at 20% reached, the fiber shows the failure to bond with matrix due to the proportion of the composites.

CHAPTER 6: RECOMMENDATION

As for the recommendation for this project, the weak bonding can be improved by using the coupling agent such as Silane Coupling Agents and Titanate Couplers. Coupling agent is a chemical substance that capable to react with both the reinforcement and the resin matrix of a composite material to form or promote a stronger bond at the interface. Other than that, the study of fibrous composites can be change into filler composites since using the fiber can cause burning during the process. The treatment of the fiber should decrease the weight and become lighter than matrix. It is also can be recommend to change the matrix by using the low melting point of polymer. The suitable matrix that can be used is the polystyrene epoxy resin.

REFERENCES

1. Kuruvilla Joseph, Romildo Dias Tolêdo Filho, Beena James, Sabu Thomas & Laura Hecker de Carvalho, 1999, *A REVIEW ON SISAL FIBER REINFORCED POLYMER COMPOSITES*, Campina Grande, PB, DEAg/UFPB

2. A R Bunsell and J Renard, 2005, *Fundamentals of Fibre Reinforced Composite Materials,* Institute of Physics, Series in Materials Science and Engineering.

3. Muhamad F. Arif, *Mechanical and Water Absorption Properties of Oil Palm Fruit Bunch- High Density Polyethylene Composites: Influence of Chemical Treatments,* M.S Thesis, 2008, University Teknologi Petronas.

4. Definition of composite materials from World Wide Web <http://www.wisegeek.com/what-are-composite-materials.htm >

5. M. S. SREEKALA, M. G. KUMARAN, SEENA JOSEPH and MAYA JACOB *,Oil Palm Fibre Reinforced Phenol Formaldehyde Composites: Influence of Fibre Surface Modifications on the Mechanical Performance*, Rubber Research Institute of India, Kottayam, Kerala, India 686 009

6. Definition and Properties of Polystyrene from World Wide Web: <http://en.wikipedia.org/wiki/Polystyrene>

7. Articles,Short Fiber Reinforced Composites: The Effect on Fiber Length and Volume Fraction from World Wide Web: <http://www.thejcdp.com/issue029/garoushi/02garoushi.htm > access on 30th May 2009.

8. David Roylance, *INTRODUCTION TO COMPOSITE MATERIALS*, Department of Materials Science and Engineering Massachusetts Institute of Technology Cambridge, MA 02139 March 24, 2000

9. Jones R. M. 1998. *Mechanics of composite materials*. 2nd Ed. Edwards Brothers, Ann Arbor.

10. Donald R. Askeland and Pradeep P. Phulé, 2003, *The Science and Engineering of Materials, Forth Edition,* Thomson Brooks/Cole

11. Process and Properties of Injection Molding from World Wide Web <http://www.cheresources.com/injectionzz.shtml >

12. Geochemical Instrumentation and Analysis of Scanning Electron Microscopy (SEM), access on 30th May 2009 from World Wide Web <http://serc.carleton.edu/research_education/geochemsheets/techniques/SEM.html >

13. Zhao, Y.H. and Weng, G.J. (1997), "*Transversely isotropic moduli of two partially debonded composites*", Department of Mechanical and Aerospace Engineering, Rutgers University, New Brunswick, New Jersey 08903, ETATS-UNIS

Gantt Chart for first Semester FYP

No	Detail / Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of Project Topic	■	■						MID SEMESTER							
2	Preliminary Research Work		■	■	■											
3	Submission of Preliminary Report				●											
4	Fundamental Theory of EFBF and PS					■	■	■								
5	Submission of Progress Report									●						
6	Seminar									●						
7	Project Work- Theory of the Project (material base)									■	■	■	■	■	■	■
8	Submission of Interim report Final draft														●	
9	Oral Presentation															●

Gantt Chart for second Semester of FYP

No	Detail / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Fiber Treatment and Preparation	■	■	■							MID SEMESTER					
2	Submission of Progress Report I				●											
3	Compounding and Injection Molding Process				■	■	■	■	■	■						
4	Submission of Progress Report II							●								
5	Seminar									●						
6	Mechanical Testing-Tensile test SEM-Microstructure Fracture											■	■			
7	Poster Exhibition													●		
8	Submission of Dissertation														●	
9	Oral Presentation															●

APPENDICES

Appendix A : Data from Tensile Test for 100% PS
Appendix B : Data from Tensile Test for 5% of Fiber
Appendix C : Data from Tensile Test for 10% of Fiber
Appendix D : Data from Tensile Test for 15% of Fiber
Appendix E : Data from Tensile Test for 20% of Fiber
Appendix F : Graph Stress vs. Strain of 100% PS
Appendix G : Graph Stress vs. Strain of 5% Fiber
Appendix H : Graph Stress vs. Strain of 10% Fiber
Appendix I : Graph Stress vs. Strain of 15% Fiber
Appendix J : Graph Stress vs. Strain of 20% Fiber
Appendix K : SEM Micrograph of 100% PS
Appendix L : SEM Micrograph of 5% Fiber
Appendix M : SEM Micrograph of 10% Fiber
Appendix N : SEM Micrograph of 15% Fiber
Appendix O : SEM Micrograph of 20% Fiber

Appendix A: Data from Tensile Test for 100% PS

	Maximum	Minimum	Mean	Median	Coefficien t	Standard	TRUE
					of Variance	Deviation	
SamplePassed							12.50 %
Gauge Length	81.000 mm	69.000 mm	79.500 mm	81.000 mm	4.99%	3.9686 mm	
Width	10.100 mm	10.000 mm	10.012 mm	10.000 mm	0.33%	0.033072 mm	
Thickness	4.0000 mm	4.0000 mm	4.0000 mm	4.0000 mm	0.00%	0.00000 mm	
Area	40.400 mm²	40.000 mm²	40.050 mm²	40.000 mm²	0.33%	0.13229 mm²	
Speed	50.000 mm/min	5.0000 mm/min	15.000 mm/min	10.000 mm/min	89.75%	13.463 mm/min	
Break							75.00 %
Stiffness	785000 N/m	105000 N/m	535000 N/m	703000 N/m	53.62%	287000 N/m	
Young's Modulus	1589.8 MPa	212.12 MPa	1072.8 MPa	1424.5 MPa	55.12%	591.30 MPa	
Load at Maximum	1910.1 N	88.752 N	1301.2 N	1872.7 N	60.01%	780.80 N	
Extension at Maximum	19.788 mm	1.0281 mm	6.0150 mm	3.0489 mm	100.89%	6.0688 mm	
Tensile Strength	47.752 MPa	2.2188 MPa	32.524 MPa	46.816 MPa	60.04%	19.528 MPa	
Percentage Strain at Maximum	28.678	1.2692	7.957	3.7641	109.68%	8.7274	
Work to Maximum	6.0650 J	0.054195 J	2.8356 J	2.9332 J	56.84%	1.6118 J	
Load at Break	1910.1 N	688.34 N	1691.8 N	1890.1 N	26.54%	449.02 N	
Extension at Break	12.409 mm	2.5321 mm	4.6270 mm	3.0489 mm	75.99%	3.5159 mm	

Stress at Break	47.752 MPa	17.209 MPa	42.295 MPa	47.253 MPa	26.54%	11.225 MPa	
Percentage Strain at Break	15.32	3.1261	5.7124	3.7641	75.99%	4.3406	
Work to Break	6.3805 J	2.5621 J	3.5850 J	3.1736 J	35.75%	1.2817 J	
Tensile Energy to Break	1.9693 MJ/m^3	0.79076 MJ/m^3	1.1065 MJ/m^3	0.97951 MJ/m^3	35.75%	0.39560 MJ/m^3	
Breaking Factor	191010 N/m	69019.0 N/m	169210 N/m	189010 N/m	26.50%	44833.0 N/m	
Load at Yield	685.51 N	82.594 N	285.62 N	88.752 N	99.00%	282.78 N	
Extension at Yield	10.602 mm	1.0030 mm	4.2111 mm	1.0281 mm	107.32%	4.5193 mm	
Stress at Yield	17.138 MPa	2.0444 MPa	7.1336 MPa	2.2188 MPa	99.17%	7.0743 MPa	
Percentage Strain at Yield	13.089	1.2692	5.2707	1.4536	104.90%	5.5291	
Work to Yield	5.1372 J	0.044004 J	1.7451 J	0.054195 J	137.44%	2.3985 J	
Load at Lower Yield	74.446 N	58.985 N	66.716 N	66.716 N	11.59%	7.7308 N	
Extension at Lower Yield	2.6145 mm	1.1347 mm	1.8746 mm	1.8746 mm	39.47%	0.73993 mm	
Stress at Lower Yield	1.8427 MPa	1.4746 MPa	1.6587 MPa	1.6587 MPa	11.10%	0.18406 MPa	
Percentage Strain at Lower Yield	3.2278	1.6444	2.4361	2.4361	32.50%	0.79169	
Work to Lower Yield	0.16539 J	0.054342 J	0.10987 J	0.10987 J	50.54%	0.055526 J	
Load at Offset Yield	1899.0 N	24.056 N	1143.7 N	1862.6 N	75.58%	864.41 N	
Extension at Offset Yield	3.9077 mm	0.19667 mm	2.2713 mm	2.5809 mm	51.46%	1.1688 mm	
Stress at Offset Yield	47.475 MPa	0.59544 MPa	28.591 MPa	46.566 MPa	75.59%	21.611 MPa	
Percentage Strain at Offset Yield	4.8244	0.28503	2.8101	3.1863	50.97%	1.4323	
Work to Offset Yield	3.3016 J	0.0038969 J	1.6993 J	2.6739 J	79.49%	1.3507 J	
Number of Rows that Passed	1						
Number of Rows that Failed	7						

Appendix B: Data from Tensile Test for 5% of Fiber

	Maximum	Minimum	Mean	Median	Coefficient of Variance	Standard Deviation	TRUE
Sample Passed							100.00 %
Gauge Length	81.000 mm	81.000 mm	81.000 mm	81.000 mm	0.00%	0.00000 mm	
Width	10.000 mm	10.000 mm	10.000 mm	10.000 mm	0.00%	0.00000 mm	
Thickness	4.0000 mm	4.0000 mm	4.0000 mm	4.0000 mm	0.00%	0.00000 mm	
Area	40.000 mm^2	40.000 mm^2	40.000 mm^2	40.000 mm^2	0.00%	0.00000 mm^2	
Speed	10.000 mm/min	10.000 mm/min	10.000 mm/min	10.000 mm/min	0.00%	0.00000015805 mm/min	
Break							100.00 %
Stiffness	449000 N/m	219000 N/m	379000 N/m	396000 N/m	19.12%	72500 N/m	
Young's Modulus	908.90 MPa	443.24 MPa	768.04 MPa	802.04 MPa	19.12%	146.84 MPa	
Load at Maximum	1269.5 N	87.689 N	887.79 N	1102.1 N	50.91%	451.98 N	
Extension at Maximum	5.3812 mm	0.93951 mm	3.8508 mm	4.3238 mm	36.65%	1.4114 mm	
Tensile Strength	31.738 MPa	2.1922 MPa	22.195 MPa	27.552 MPa	50.91%	11.300 MPa	
Percentage Strain at Maximum	6.6435	1.1599	4.754	5.338	36.65%	1.7425	
Work to Maximum	2.4215 J	0.036501 J	1.4595 J	1.7874 J	56.92%	0.83072 J	
Load at Break	1269.5 N	35.698 N	869.36 N	1102.1 N	55.57%	483.10 N	
Extension at Break	18.200 mm	3.2849 mm	6.4130 mm	4.9659 mm	70.46%	4.5189 mm	
Stress at Break	31.738 MPa	0.89245 MPa	21.734 MPa	27.552 MPa	55.57%	12.077 MPa	

Percentage Strain at Break	22.469	4.0554	7.9172	6.1307	70.46%	5.5788	
Work to Break	2.4215 J	0.45790 J	1.6131 J	1.7874 J	37.11%	0.59868 J	
Tensile Energy to Break	0.74738 MJ/m^3	0.14133 MJ/m^3	0.49787 MJ/m^3	0.55166 MJ/m^3	37.11%	0.18478 MJ/m^3	
Breaking Factor	126950 N/m	8768.9 N/m	88779.0 N/m	110210 N/m	50.91%	45198.0 N/m	
Load at Yield	127.25 N	87.689 N	107.47 N	107.47 N	18.41%	19.781 N	
Extension at Yield	2.0651 mm	0.93951 mm	1.5023 mm	1.5023 mm	37.46%	0.56278 mm	
Stress at Yield	3.1813 MPa	2.1922 MPa	2.6867 MPa	2.6867 MPa	18.41%	0.49452 MPa	
Percentage Strain at Yield	2.5495	1.1599	1.8547	1.8547	37.46%	0.69479	
Work to Yield	0.090390 J	0.036501 J	0.063446 J	0.063446 J	42.47%	0.026945 J	
Load at Lower Yield	98.341 N	73.194 N	85.768 N	85.768 N	14.66%	12.574 N	
Extension at Lower Yield	2.1948 mm	1.2428 mm	1.7188 mm	1.7188 mm	27.69%	0.47600 mm	
Stress at Lower Yield	2.4585 MPa	1.8298 MPa	2.1442 MPa	2.1442 MPa	14.66%	0.31434 MPa	
Percentage Strain at Lower Yield	2.7096	1.5343	2.1219	2.1219	27.69%	0.58765	
Work to Lower Yield	0.10470 J	0.060845 J	0.082772 J	0.082772 J	26.49%	0.021928 J	
Load at Offset Yield	97.354 N	86.465 N	91.909 N	91.909 N	5.92%	5.4449 N	
Extension at Offset Yield	1.7658 mm	0.98394 mm	1.3749 mm	1.3749 mm	28.44%	0.39095 mm	
Stress at Offset Yield	2.4339 MPa	2.1616 MPa	2.2977 MPa	2.2977 MPa	5.92%	0.13612 MPa	
Percentage Strain at Offset Yield	2.1801	1.2147	1.6974	1.6974	28.44%	0.48266	
Work to Offset Yield	0.057414 J	0.040370 J	0.048892 J	0.048892 J	17.43%	0.0085224 J	
Number of Rows that Passed	8						

Appendix C: Data from Tensile Test for 10% of Fiber

	Maximum	Minimum	Mean	Median	Coefficient	Standard	TRUE
					of Variance	Deviation	
SamplePassed							100.00%
Gauge Length	81.000 mm	81.000 mm	81.000 mm	81.000 mm	0.00%	0.00000 mm	
Width	10.000 mm	10.000 mm	10.000 mm	10.000 mm	0.00%	0.00000 mm	
Thickness	4.0000 mm	4.0000 mm	4.0000 mm	4.0000 mm	0.00%	0.00000 mm	
Area	40.000 mm²	40.000 mm²	40.000 mm²	40.000 mm²	0.00%	0.00000 mm²	
Speed	10.000 mm/min	10.000 mm/min	10.000 mm/min	10.000 mm/min	0.00%	0.00000 mm/min	
Break							100.00%
Stiffness	810000 N/m	381000 N/m	532000 N/m	468000 N/m	31.81%	169000 N/m	
Young's Modulus	1640.1 MPa	771.53 MPa	1077.3 MPa	948.67 MPa	31.81%	342.64 MPa	
Load at Maximum	1145.1 N	749.73 N	1014.0 N	1080.6 N	15.29%	155.09 N	
Extension at Maximum	4.9347 mm	2.3699 mm	3.7168 mm	3.7812 mm	24.64%	0.91582 mm	
Tensile Strength	28.628 MPa	18.743 MPa	25.350 MPa	27.015 MPa	15.29%	3.8773 MPa	
Percentage Strain at Maximum	6.0922	2.9258	4.5886	4.6682	24.64%	1.1306	
Work to Maximum	1.8119 J	0.99080 J	1.4418 J	1.4822 J	20.82%	0.30014 J	
Load at Break	1145.1 N	749.73 N	1014.0 N	1080.6 N	15.29%	155.09 N	
Extension at Break	4.9347 mm	2.3699 mm	3.7168 mm	3.7812 mm	24.64%	0.91582 mm	
Stress at Break	28.628 MPa	18.743 MPa	25.350 MPa	27.015 MPa	15.29%	3.8773 MPa	
Percentage Strain at Break	6.0922	2.9258	4.5886	4.6682	24.64%	1.1306	
Work to Break	1.8119 J	0.99080 J	1.4418 J	1.4822 J	20.82%	0.30014 J	

Tensile Energy to Break	0.55923 MJ/m^3	0.30580 MJ/m^3	0.44500 MJ/m^3	0.45748 MJ/m^3	20.82%	0.092634 MJ/m^3	
Breaking Factor	114510 N/m	74973.0 N/m	101400 N/m	108060 N/m	15.29%	15509.0 N/m	
Load at Offset Yield	206.05 N	206.05 N	206.05 N	206.05 N	0.00%	0.00000 N	
Extension at Offset Yield	0.41171 mm	0.41171 mm	0.41171 mm	0.41171 mm	0.00%	0.00000 mm	
Stress at Offset Yield	5.1514 MPa	5.1514 MPa	5.1514 MPa	5.1514 MPa	0.00%	0.00000 MPa	
Percentage Strain at Offset Yield	0.50829	0.50829	0.50829	0.50829	0.00%	0	
Work to Offset Yield	0.053838 J	0.053838 J	0.053838 J	0.053838 J	0.00%	0.00000 J	
Number of Rows that Passed	4						
Number of Rows that Failed	0						

Appendix D: Data from Tensile Test for 15% of Fiber

	Maximum	Minimum	Mean	Median	Coefficient of Variance	Standard Deviation	TRUE
Sample Passed							100.00 %
Gauge Length	81.000 mm	81.000 mm	81.000 mm	81.000 mm	0.00%	0.00000 mm	
Width	10.000 mm	10.000 mm	10.000 mm	10.000 mm	0.00%	0.00000 mm	
Thickness	4.0000 mm	4.0000 mm	4.0000 mm	4.0000 mm	0.00%	0.00000 mm	
Area	40.000 mm^2	40.000 mm^2	40.000 mm^2	40.000 mm^2	0.00%	0.00000 mm^2	
Speed	10.000 mm/min	5.0000 mm/min	9.1667 mm/min	10.000 mm/min	20.33%	1.8634 mm/min	
Break							100.00 %
Stiffness	832000 N/m	441000 N/m	543000 N/m	500000 N/m	24.99%	136000 N/m	
Young's Modulus	1685.2 MPa	893.11 MPa	1099.3 MPa	1012.2 MPa	24.99%	274.68 MPa	
Load at Maximum	1269.5 N	719.09 N	1122.5 N	1206.4 N	16.98%	190.65 N	
Extension at Maximum	5.5397 mm	1.6520 mm	4.0061 mm	4.0414 mm	32.93%	1.3191 mm	
Tensile Strength	31.737 MPa	17.977 MPa	28.061 MPa	30.160 MPa	16.98%	4.7662 MPa	
Percentage Strain at Maximum	6.8391	2.0395	4.9458	4.9894	32.93%	1.6285	
Work to Maximum	2.0145 J	0.66482 J	1.5734 J	1.6705 J	28.44%	0.44752 J	
Load at Break	1269.5 N	719.09 N	1122.5 N	1206.4 N	16.98%	190.65 N	
Extension at Break	5.5397 mm	1.6520 mm	4.0061 mm	4.0414 mm	32.93%	1.3191 mm	
Stress at Break	31.737 MPa	17.977 MPa	28.061 MPa	30.160 MPa	16.98%	4.7662 MPa	
Percentage Strain at Break	6.8391	2.0395	4.9458	4.9894	32.93%	1.6285	

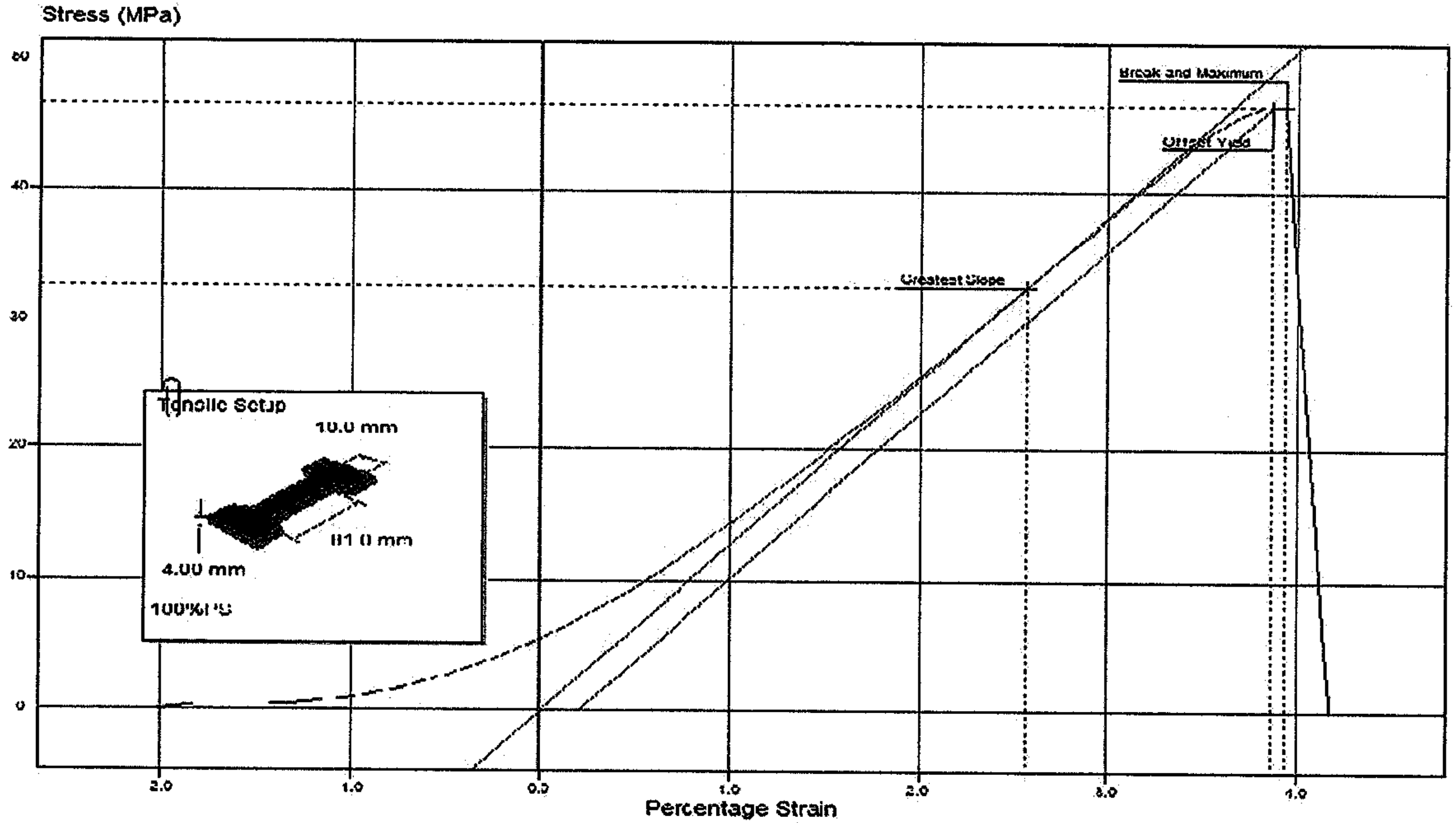
Work to Break	2.0145 J	0.66482 J	1.5734 J	1.6705 J	28.44%	0.44752 J	
Tensile Energy to Break	0.62174 MJ/m^3	0.20519 MJ/m^3	0.48562 MJ/m^3	0.51559 MJ/m^3	28.44%	0.13812 MJ/m^3	
Breaking Factor	126950 N/m	71909.0 N/m	112250 N/m	120640 N/m	16.98%	19065.0 N/m	
Load at Offset Yield	263.55 N	263.55 N	263.55 N	263.55 N	0.00%	0.00000 N	
Extension at Offset Yield	0.47268 mm	0.47268 mm	0.47268 mm	0.47268 mm	0.00%	0.00000 mm	
Stress at Offset Yield	6.5889 MPa	6.5889 MPa	6.5889 MPa	6.5889 MPa	0.00%	0.00000 MPa	
Percentage Strain at Offset Yield	0.58356	0.58356	0.58356	0.58356	0.00%	0	
Work to Offset Yield	0.072084 J	0.072084 J	0.072084 J	0.072084 J	0.00%	0.00000 J	
Number of Rows that Passed	6						
Number of Rows that Failed	0						

Appendix E: Data from Tensile Test for 20% of Fiber

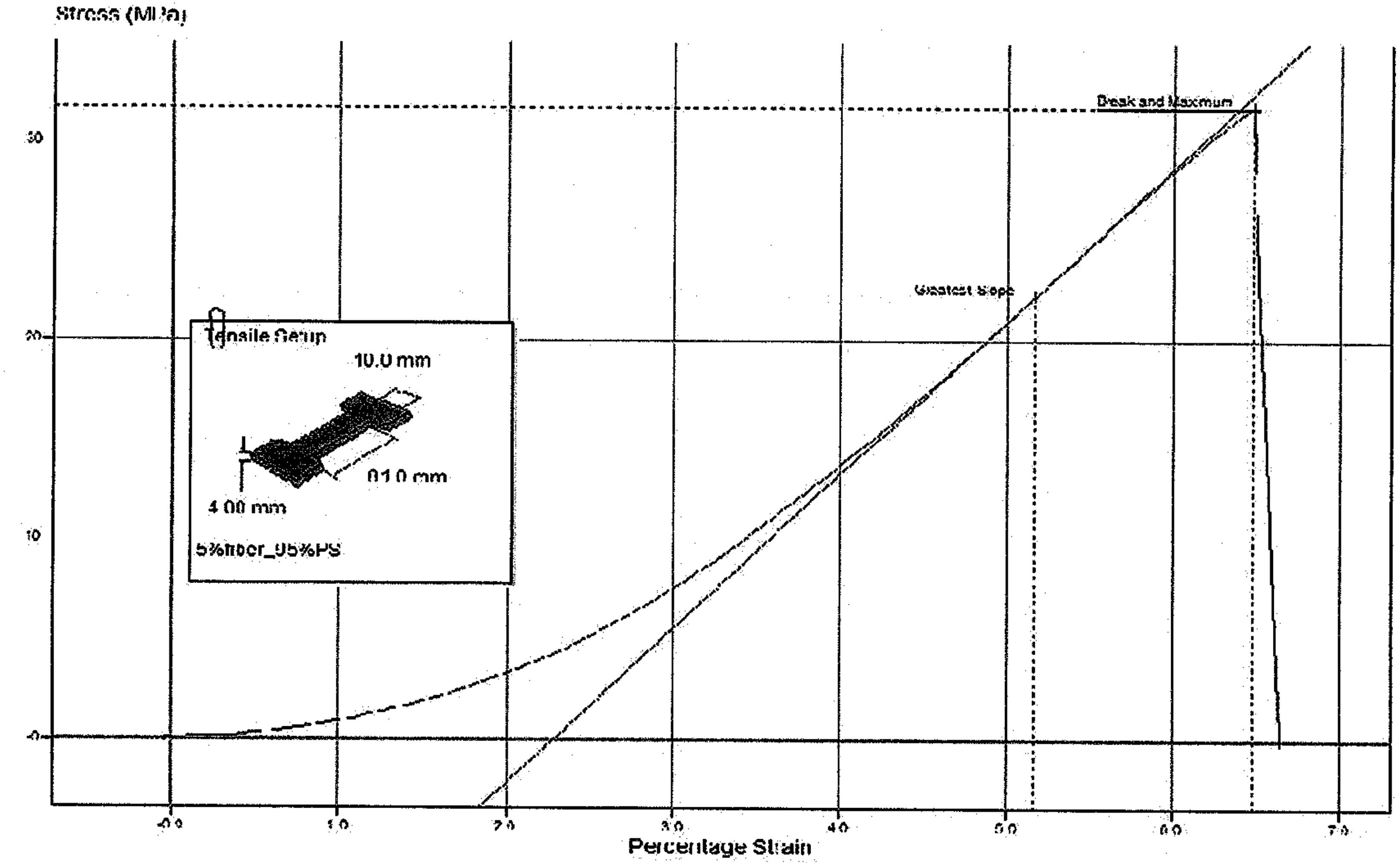
	Maximum	Minimum	Mean	Median	Coefficient of Variance	Standard Deviation	TRUE
Sample Passed							100.00%
Gauge Length	81.000 mm	81.000 mm	81.000 mm	81.000 mm	0.00%	0.00000 mm	
Width	10.000 mm	10.000 mm	10.000 mm	10.000 mm	0.00%	0.00000 mm	
Thickness	4.0000 mm	4.0000 mm	4.0000 mm	4.0000 mm	0.00%	0.00000 mm	
Area	40.000 mm^2	40.000 mm^2	40.000 mm^2	40.000 mm^2	0.00%	0.00000 mm^2	
Speed	5.0000 mm/min	5.0000 mm/min	5.0000 mm/min	5.0000 mm/min	0.00%	0.00000 mm/min	
Break							100.00%
Stiffness	609000 N/m	231000 N/m	420000 N/m	420000 N/m	44.99%	189000 N/m	
Young's Modulus	1232.4 MPa	467.60 MPa	850.00 MPa	850.00 MPa	44.99%	382.40 MPa	
Load at Maximum	796.65 N	380.44 N	588.54 N	588.54 N	35.36%	208.10 N	
Extension at Maximum	5.3107 mm	1.2471 mm	3.2789 mm	3.2789 mm	61.97%	2.0318 mm	
Tensile Strength	19.916 MPa	9.5110 MPa	14.714 MPa	14.714 MPa	35.36%	5.2026 MPa	
Percentage Strain at Maximum	6.5564	1.5396	4.048	4.048	61.97%	2.5084	
Work to Maximum	1.6136 J	0.27362 J	0.94359 J	0.94359 J	71.00%	0.66997 J	
Load at Break	796.65 N	380.44 N	588.54 N	588.54 N	35.36%	208.10 N	
Extension at Break	5.3107 mm	1.2471 mm	3.2789 mm	3.2789 mm	61.97%	2.0318 mm	
Stress at Break	19.916 MPa	9.5110 MPa	14.714 MPa	14.714 MPa	35.36%	5.2026 MPa	
Percentage Strain at Break	6.5564	1.5396	4.048	4.048	61.97%	2.5084	
Work to Break	1.6136 J	0.27362 J	0.94359 J	0.94359 J	71.00%	0.66997 J	
Tensile Energy to Break	0.49801	0.084450	0.29123	0.29123	71.00%	0.20678	

	MJ/m^3	MJ/m^3	MJ/m^3	MJ/m^3		MJ/m^3	
Breaking Factor	79665.0 N/m	38044.0 N/m	58854.0 N/m	58854.0 N/m	35.36%	20810.0 N/m	
Load at Offset Yield	184.84 N	184.84 N	184.84 N	184.84 N	0.00%	0.00000 N	
Extension at Offset Yield	0.45750 mm	0.45750 mm	0.45750 mm	0.45750 mm	0.00%	0.00000 mm	
Stress at Offset Yield	6.5889 MPa	6.5889 MPa	6.5889 MPa	6.5889 MPa	0.00%	0.00000 MPa	
Percentage Strain at Offset Yield	0.58356	0.58356	0.58356	0.58356	0.00%	0	
Work to Offset Yield	0.072084 J	0.072084 J	0.072084 J	0.072084 J	0.00%	0.00000 J	
Number of Rows that Passed	3						
Number of Rows that Failed	0						

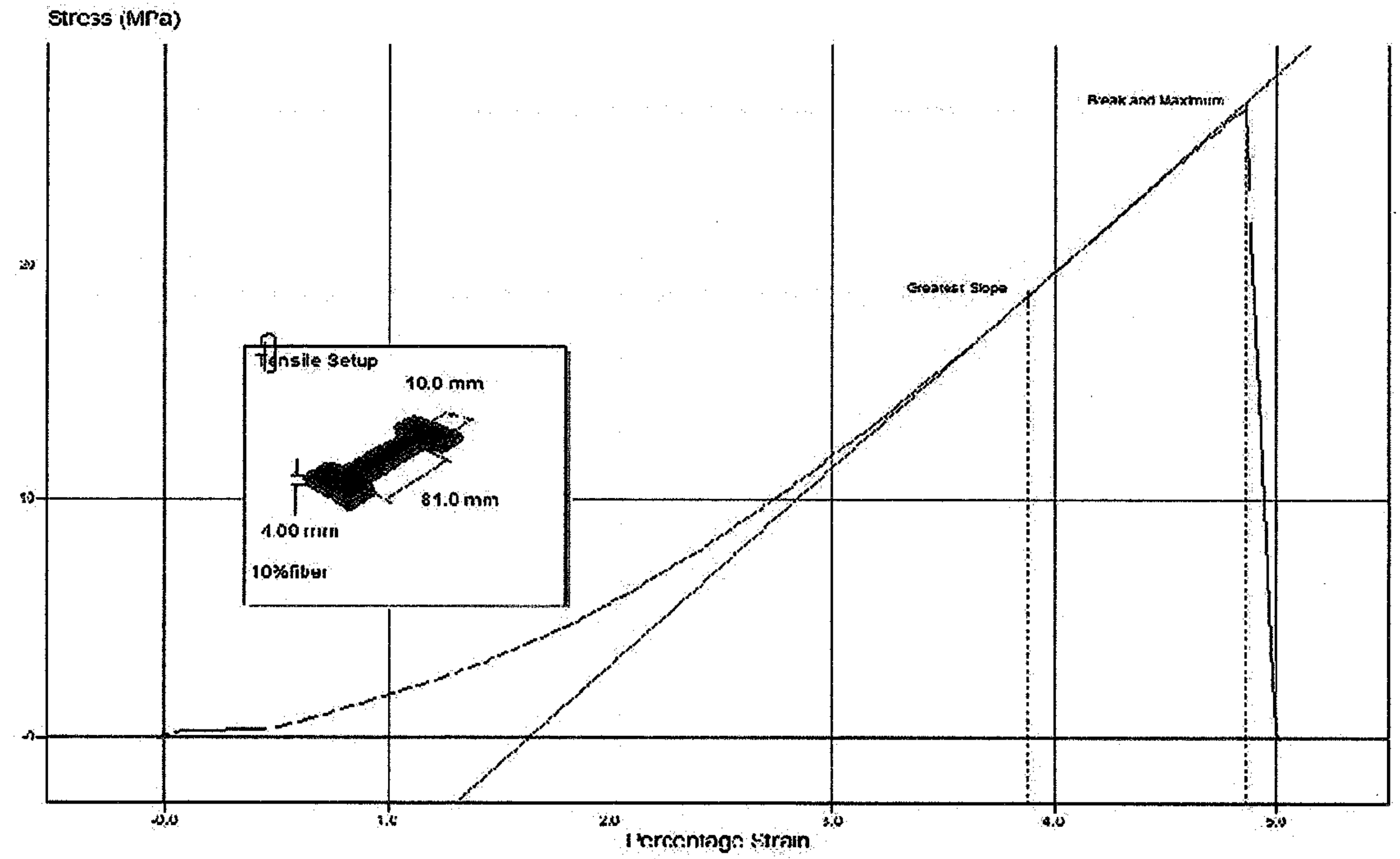
Appendix F: Graph Stress vs. Strain of 100% PS



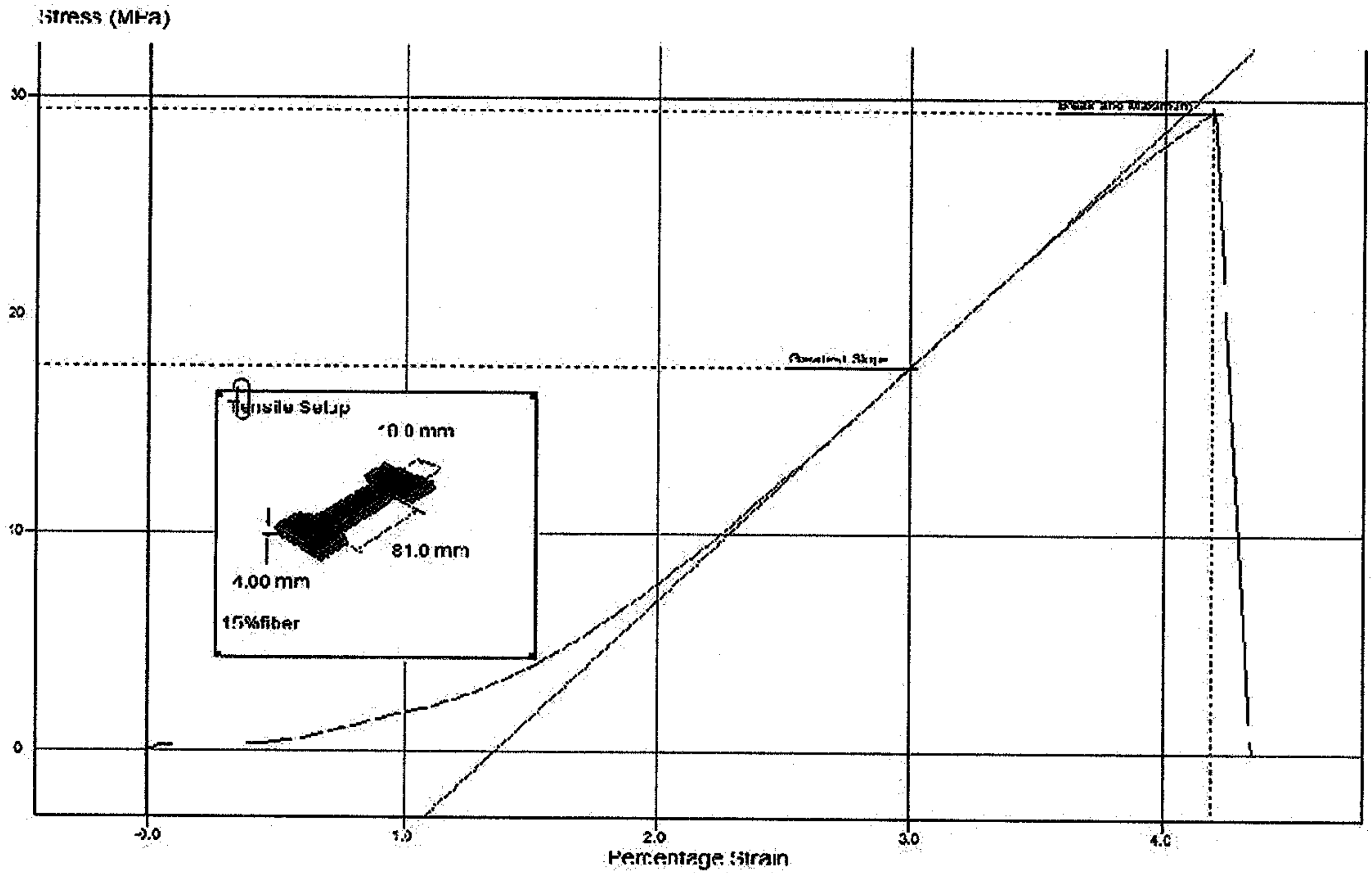
Appendix G: Graph Stress vs. Strain of 5% Fiber



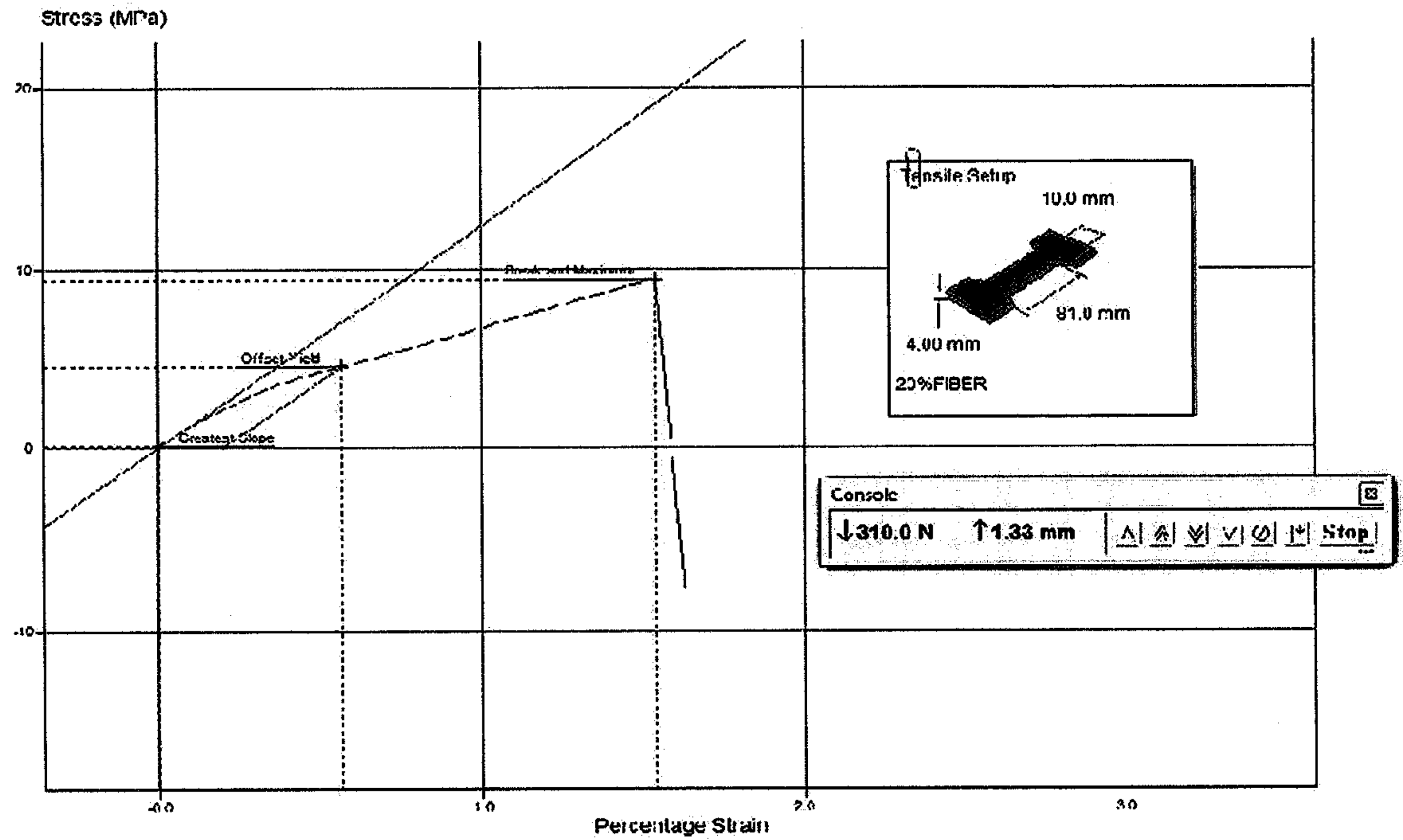
Appendix H: Graph Stress vs. Strain of 10% Fiber



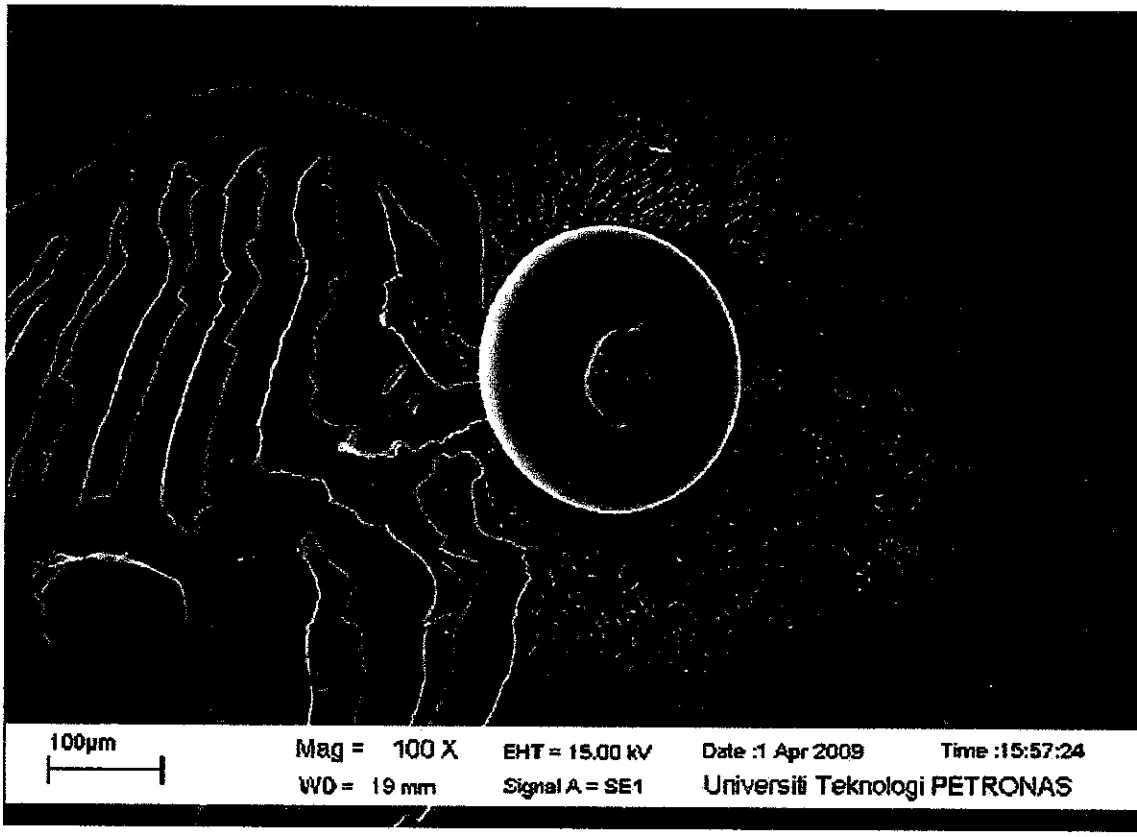
Appendix I: Graph Stress vs. Strain of 15% Fiber



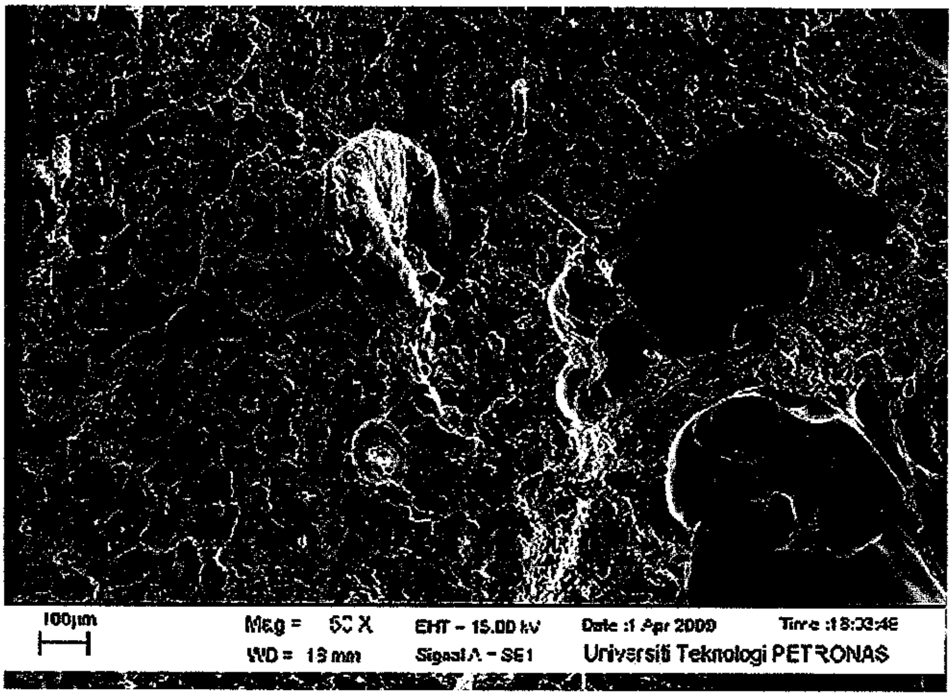
Appendix J: Graph Stress vs. Strain of 20% Fiber

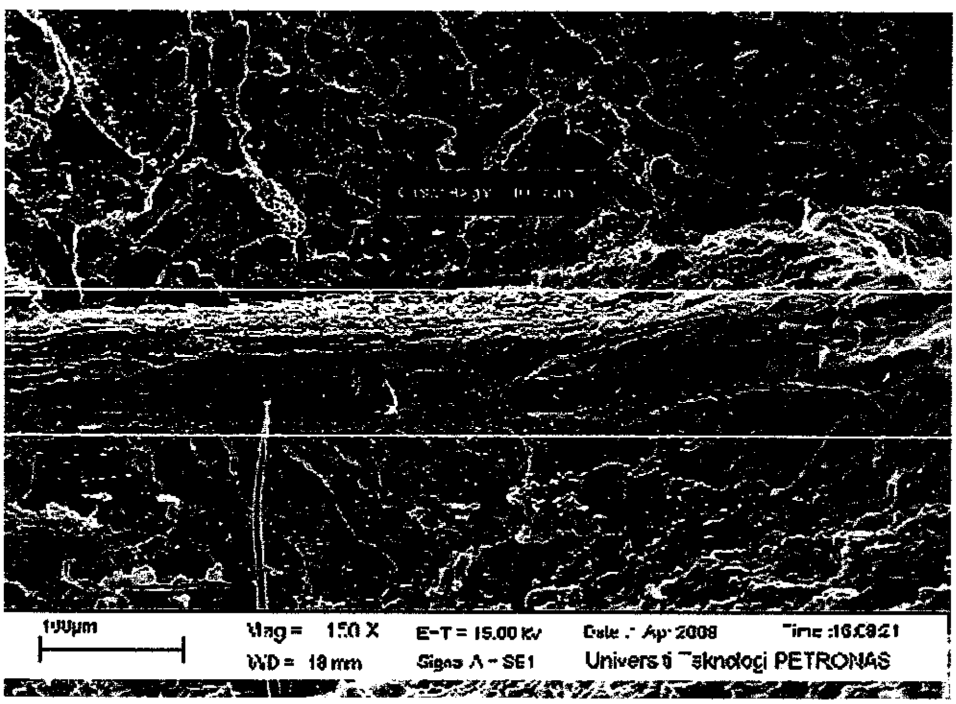


Appendix K: SEM Micrograph of 100% PS

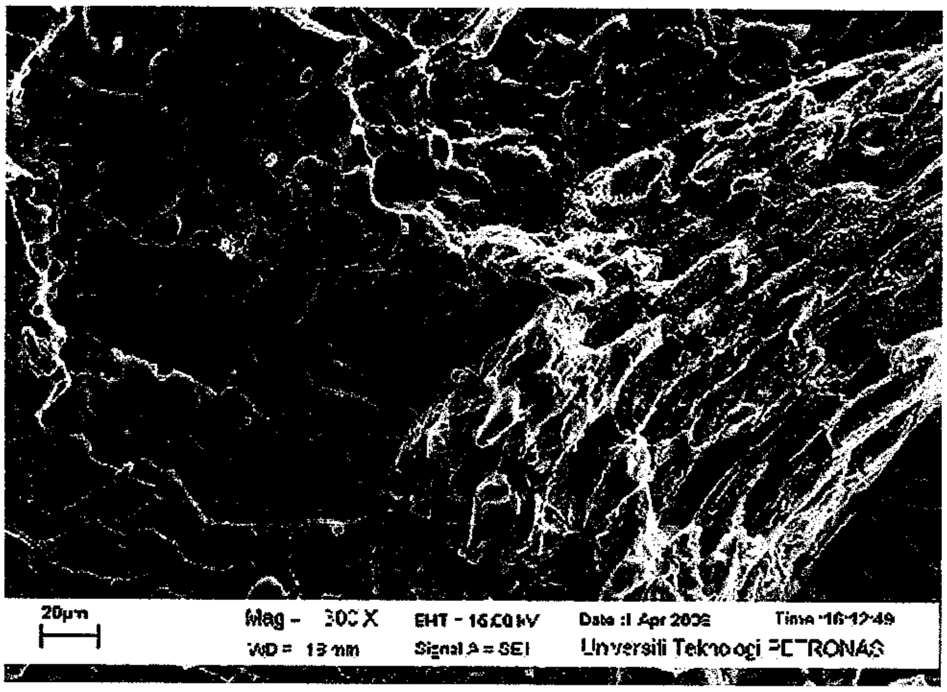


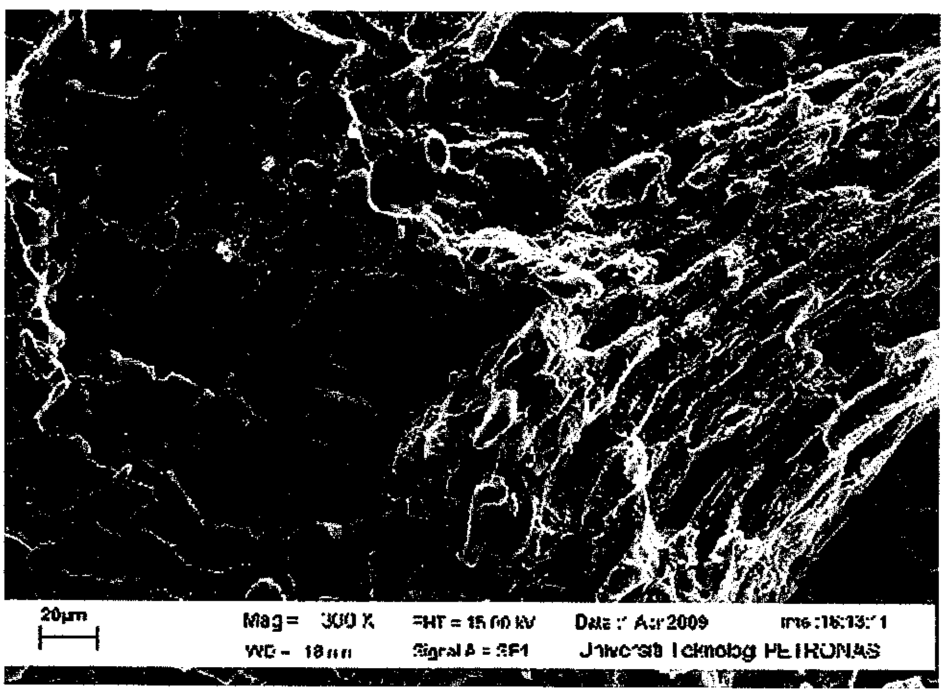
Appendix L: SEM Micrograph of 5% Fiber



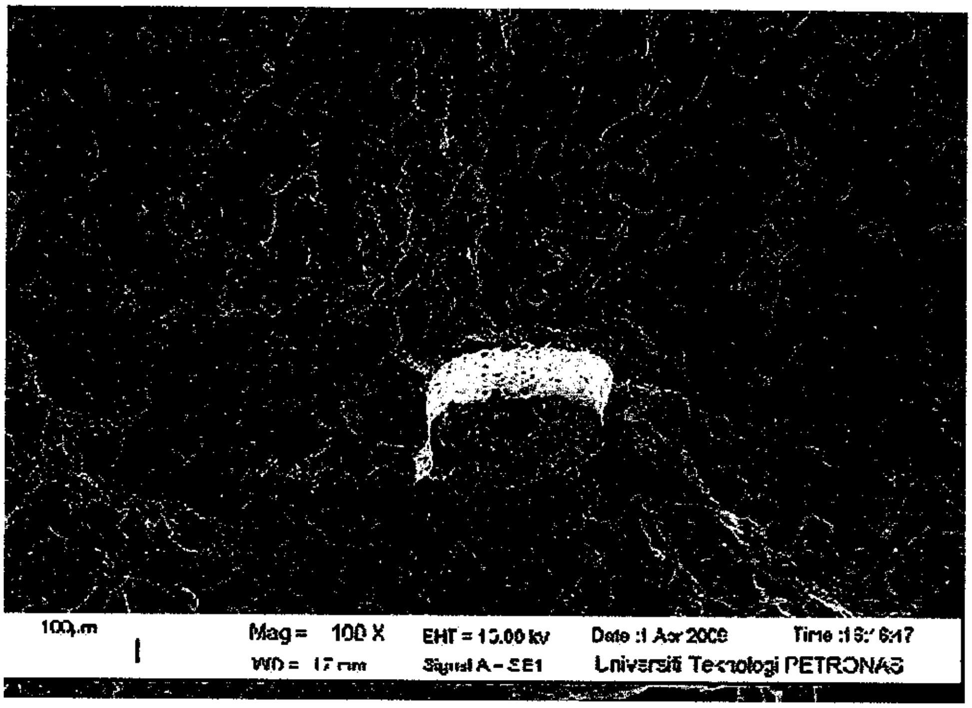


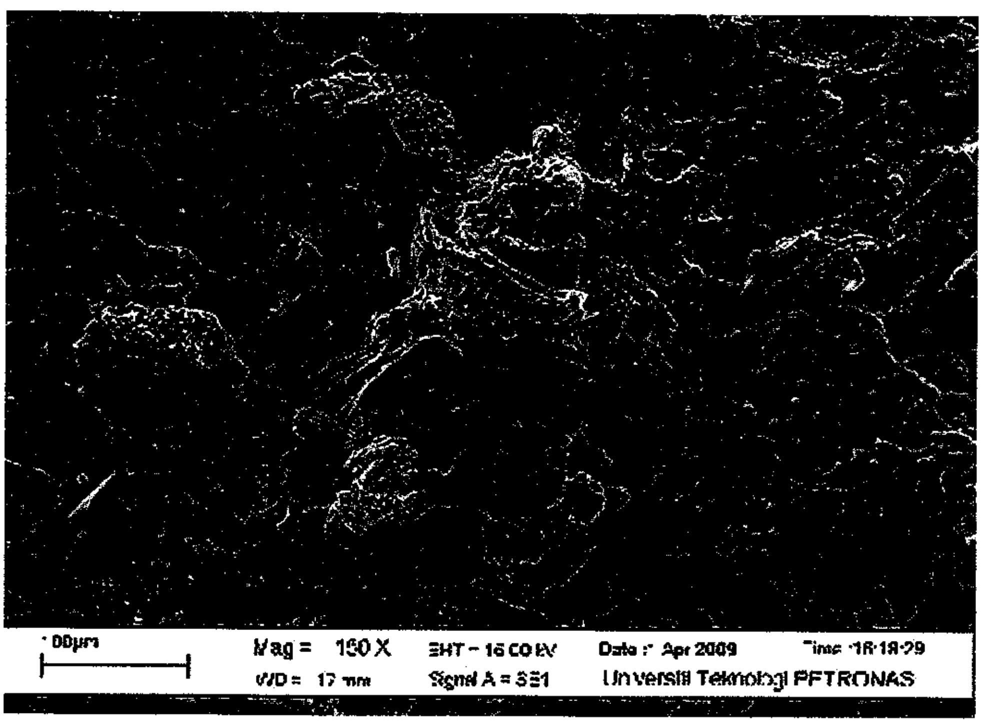
Appendix M: SEM Micrograph of 10% Fiber





Appendix N: SEM Micrograph of 15% Fiber





Appendix O: SEM Micrograph of 20% Fiber