DEVELOPMENT OF BANANA FIBERS REINFORCED EPOXY-GYPSUM COMPOSITE

by

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Dissertation submitted in partial fulfilment of
the requirements for the
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CERTIFICATION OF APPROVAL

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Approved:

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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.

Syarifuddin bin Seban

ABSTRACT

Banana fiber composites are developed from banana fiber of Pisang Abu, epoxy and gypsum. The banana fibers were extracted and dried at 60^0C. The composites were test for 30vol% and 40vol% of long and short fiber to determine the effect of fiber length and the optimum fiber content. At 10vol% and 20vol% of gypsum added to the short fiber composite, the mechanical properties of the composite are different. All samples were tested for flexural strength and Scanning Electron Microscopic (SEM) at the fracture surface. A very high architectural art design pose in the composites will add value and make it more commercialize. Other that that, lots of applications can be developed from using banana fiber reinforce epoxy-gypsum composite.

ACKNOWLEDGEMENT

Alhamdulillah, for His blessing and mercy, I manage to finish my Final Year Project. I would like to give my highest appreciation to my project supervisor; AP. Dr. Zakaria Bin Man, who become my important contact person for support and guidance during FYP1 and FYP 2 in Universiti Teknologi PETRONAS

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Finally yet importantly, a grateful thanks to other persons not mentioned above. The author will not forget all the contribution that all of you have done for me for the rest of my life. The author sincerely would like to apologize for any mistaken that the author made accidentally during the completion of this project.

"See you at the top"
Syarifuddin bin Seban

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LIST OF ABBREVIATIONS

DGEBA : Di-Glycidyl Ether of Bisphenol A
MARDI : Malaysian Agricultural Research and Development Institute
FAMA : Federal Agriculture Marketing Authority (FAMA)
KUKAM : Koperasi Usahawan Kampung Balik Pulau, Penang
SEM : Scanning Electron Microscopic
T_g : Glass Transition Temperature

CHAPTER 1
INTRODUCTION

1.1 Background

Extensive research work has been carried out on the natural fiber reinforced composite materials in many applications for years. These applications are environmental friendly materials which are potentially user friendly. Moreover, the global trends indicate that the marketplace is leaning to the natural fiber use because of its environmental friendly such as renewable; recyclable; very low cost material. [4] There has been increased interest in the sourcing of cheaper raw material in this application and natural fibers from plants are beginning to find their way into commercial applications such as automotive industries, household applications, etc. Since the natural fibers such as banana fibers are available in abundance in nature and can be used to reinforce polymers to obtain light and strong materials, the opportunity to commercialize the natural fiber is a need.

Banana is the second most widely cultivated fruit in Malaysia due to the suitable climates for banana growth. Yet the abundances of banana wastes that need to be disposed at the land field and huge stocks are getting accumulated in banana growing area can be utilized. In this project, epoxy resin and gypsum powder will be used in producing banana fibers composite. The composite will be tested to determining the performance in the flexural strength test and its Scanning Electron Microscopic (SEM).

1.2 Problem statement

Banana is the second most widely cultivated fruit in Malaysia, covering about 26,000 ha with a total production of 530,000 metric tons per year and Malaysia is in the rank 21st of the exports banana fruits in the world. In general, there will be 2200 banana trees with a distance 2m x 2m for 1ha of banana plantations and most of it does not utilize the potential of banana trunk/stem (waste) for anything after harvesting the banana fruit where it will be left at the field or burn. This is the problem that farmers faced for years where the banana wastes need to be disposed at the land field and these huge stocks are getting accumulated in banana growing area. These wastes have rich cellulose and bonded by lignin to form cellulose fiber (table 2.1) hence various applications can be developed and commercialize from this opportunities

1.3 Objective and scope

Throughout this project, banana pseudo stem fiber will be the focus of the project and the objectives of the studies are:

1. To determine which part of banana trunk that has the most fiber content.
2. To extract the banana fiber from banana trunk.
3. To developed banana fiber composite
4. To determine the performances and the most optimum volume percent (vol%) of banana fiber composites under flexural test (3-point bending)
5. To determine the effect of length fiber (short or long)
6. To design any daily application from the banana fiber composite based on the performance test.

CHAPTER 2
LITERATURE REVIEW

2.1 Fiber

Fiber is a class of hair-like materials that are continuous filaments or are in discrete elongated pieces, similar to pieces of thread [9]. It can be spun into filament, thread, or rope for many products also to make component of composite material. The fibers bring the strength to the composite, the matrix binds the fibers together, transfer the loads between them and the rest of the structure.

2.1.1 Natural fiber

Natural fiber is defined as 'any of the threads or filaments forming animal or vegetable tissue and textile substances' [4] and subdivided based on their origin, whether they are derived from plant, animal or minerals (figure2.1). Banana is a leaf or hard plant fiber and yet this plant grows and has been commercialize in Malaysia.

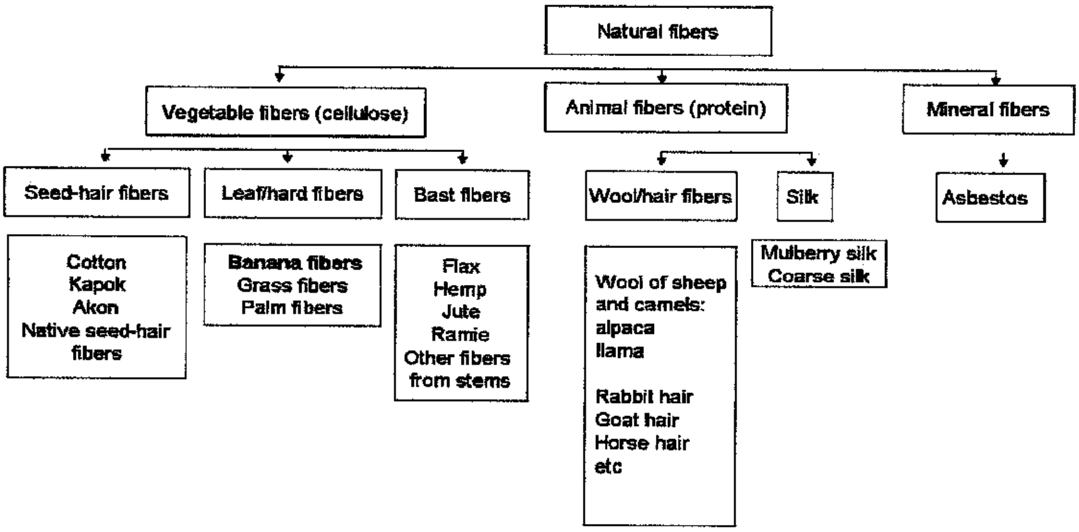


Figure 2.1: Classification of natural fibers

The fiber cells found in natural fibers are very long in relation to their width having in their cell walls a matrix or the homogeneous lattice structure of lignin and hemicellulose, with embedded cellulose micro fibrils. The layered cell wall contains varying amounts of each constituent. They are classified broadly as lignocelluloses containing 85% or more cellulose, hemicellulose and lignin, and non-lignocelluloses possessing no lignin. Each constituent makes its own contribution to the properties of the fibers.

Cellulose is a natural polymer and its structure serves as a carbon reservoir. Cellulosic fibers have a higher Young's modulus when compared to thermoplastic material; hence, they contribute a higher increment of stiffness to the composite. Cellulose is the main component of natural fibers and the elementary unit of a cellulose macromolecule is an hydro-D-glucose which contain three hydroxyl (OH) group thus all natural fiber are hydrophilic in nature. The moisture content of these fibers can vary greatly depending on the fiber type. [4][5]

The fiber/matrix interface has an important role in the micromechanical behavior of composites. Therefore, the bonding nature between the fiber and matrix depends on the atomic arrangement, chemical properties of the fiber and the chemical constitution of polymeric matrix. However, in the natural fiber composite, cellulose is the principal coupling agent in the polymer/fiber bonding. On the other hand, lignin acts obstructing the coupling agent diffusion, preventing adhesion. There are, however, several separation of fiber processing techniques such as mechanical or chemical pulping, whereby the lignin is degraded and dissolved, leaving most of the cellulose and hemicelluloses in the form of fibers. This generally has an important effect on both mechanical and chemical properties of the fibers.

Cost and availability of various natural fibers depend on the local region and import markets. The cost of natural fibers greatly depend depends on some factors such as type of fiber, location, sources, degree of refinement, and existing market. In Malaysia, the cost of natural fibers especially banana fiber will be effected by the existing market since not much banana fiber industry based in Malaysia compared to in India, Indonesia and Philippine.

Generally, natural fibers are added to plastics to improve mechanical performance such as stiffness and strength without increasing the density or cost. The significance advantages of natural fibers that very useful in this project are:

1. Low density then glass fiber
2. Renewable and recyclable
3. Low cost material

2.2 Banana

The botanical name of banana is *Musa paradisiacal; Musa Sapientum; Musa Cavendishii and Musa Chinensis etc* which are from the family Musaceae and Malaysian called it as "*pisang*". Throughout this project, Pisang Abu (*Musa acuminata Colla (AAA Group)* cv. 'Dwarf Cavendish') will be used as the banana fibers. The scientific classifications of banana are:

Kingdom : Plantae
Division : Magnoliophyta
Class : Liliopsida
Order : Zingiberales
Family : Musaceae
Genus : *Musa*

This plant is referred to as a tree but actually is a giant herb whose trunk or stem is composed of overlapping leaf bases which sheath it. Banana stems fruits only once and being replaced by new suckers which in turn flower, fruit and die (Figure 2.2). The banana plant is a pseudo stem that grows to 5 to 7.6m (16-25 feet) tall, growing from a corm. Leaves are spirally arranged and may grow 2.7m (9 ft) long and 60 cm (2 ft) wide. [21]

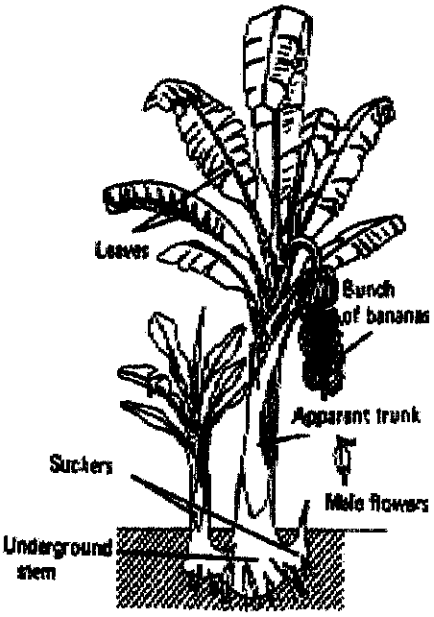


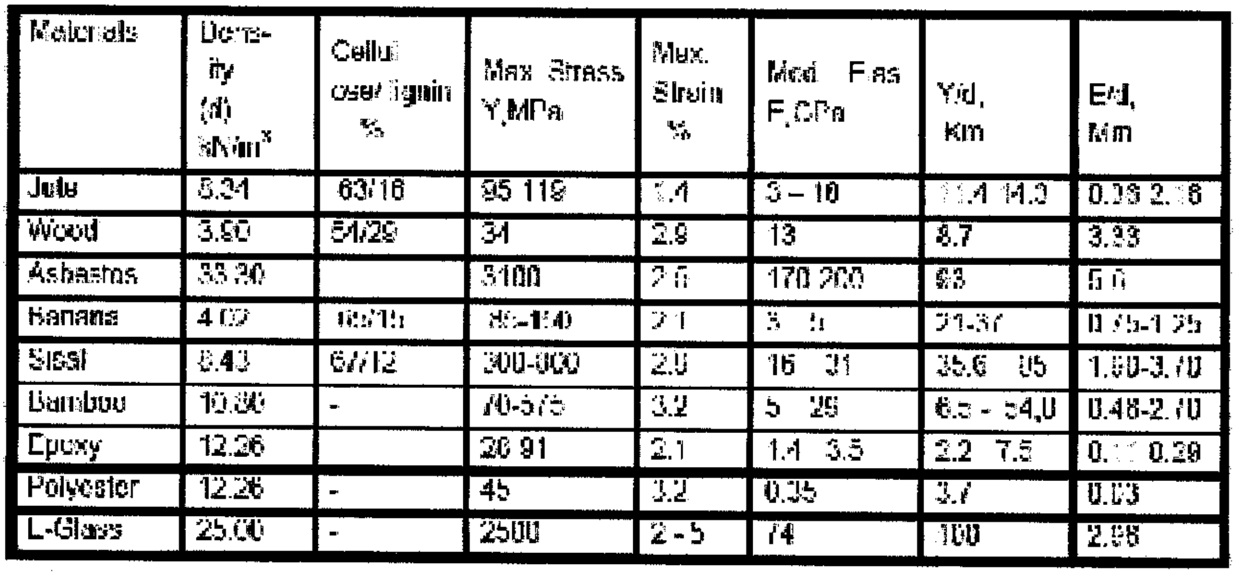
Figure 2.2: Banana plant illustration

The fruit brunch and leaves are the main source of income, besides leaves are used as bio-plate and wrapper for some food, banana fruit contains of multi vitamins and proteins. The nutrition facts of the banana are (100g pulp): carbohydrates 18,8g; roughage 2,0g; protein 1,15g; fat 0,18g; water 73,90g; vitamins C1,B1,B2 B6,E, other minerals 0,83g ; and 81 kcal.

2.2.1 Banana fiber characteristic

The independent natural fibers have poor mechanical properties compared with synthetic fibers but their reinforcement and others advantages such as availability in large quality, low density, low cost and ease to manufacture affect the potential of development of these natural fibers. Based on table 2.1, banana fiber has been selected by H.A. Al-Qureshi et al [3] to develop a truck body.

Table 2.1: Mechanical properties of some natural and synthetic fibers



Materials	Density (d) kN/m³	Cellulose/ lignin %	Max Stress Y, MPa	Max. Strain %	Mod. E as E, GPa	Y/d, Km	E/d, Mm
Jute	8.34	63/16	95 118	1.4	3 – 10	11.4 14.3	0.36 [illegible]
Wood	3.90	51/29	34	2.9	13	8.7	3.33
Asbestos	33.30		3100	2.6	170 200	93	5.6
Banana	4.02	65/15	85-140	2.1	3 5	21-37	0.75-1.25
Sisal	8.43	67/12	300-600	2.0	16 31	35.6 65	1.90-3.70
Bamboo	10.30	-	70-575	3.2	5 25	6.5 - 54.0	0.48-2.70
Epoxy	12.26		20 91	2.1	1.4 3.5	2.2 7.5	0.[illegible] 0.29
Polyester	12.26	-	45	3.2	0.35	3.7	0.03
E-Glass	25.00	-	2500	2 - 5	74	100	2.98

The chemical compositions of fibers were determined as in table 2.2 that collected from previous study by Youssef Habibi et al [8]. In table 2.2, banana plant waste exhibit the highest lignin content and lowest for cellulose. This is because the fibers were taken from plant trunk which presents high rigidity and hardness that indicating its high content of lignin. The amount of ashes in banana fiber showing that banana has high content of minerals.

Table 2.2: Chemical composition of agricultural residue

Raw material	α-cellulose	Hemicelluloses	Lignin	Ash	Wax
Bagasse	69.4	21.1	4.4	0.6	5.5
Cotton stalk	50.6	28.4	23.1	0.5	5.1
Banana plant waste	43.5	31.7	16.9	9.9	6.1
Rice straw	59.1	18.4	5.3	13.7	6.3

**As percentage of dry raw material*

Meanwhile, the physical property of banana and sisal fiber has been studied by Maries Idicula et al. as presented in table 2.3. Generally, fibers that have high cellulose content and low microfibrillar angle possess high tensile strength properties. The banana fibers tensile properties are better than sisal due to the microfibrillar angle difference. Sisal have bigger microfibrillar angle which is 20 compared to banana, 11. Furthermore, the diameter of banana fibers is lesser that sisal fiber thus the surface area of the fibers in unit area of the composite is greater that sisal fibers composite. Hence better stress transfer from matrix to fiber takes place in banana fiber composite [7]. The banana fibers itself is being strengthen by the matrixes that binds the fibers together, transfer the loads between them and the rest of the structure hold. Banana fibers reinforce with epoxy composite will be discussed and study further in this project.

Table 2.3: Physical properties of banana and sisal fiber

Physical properties of banana and sisal fiber		
Physical properties	Sisal fiber	Banana fiber
Density (g/cm3)	1.41	1.35
Elongation at break (%)	6 - 7	5 - 6
Cellulose content (%)	60-65	60-64
Lignin content (%)	10 - 14	5.00
Tensile strength (MPa)	350 ± 7	550 ± 6.7
Young modulus (GPa)	12.80	20.00
Diameter (μm)	205 ± 4.3	120 ± 5.8
Mikrofibrillar angle(°)	20.00	11.00
Lumen size (μm)	11.00	5.00

For the absorption in water test, oven is one of the equipments that been used in order to measure the percentage of moisture in fiber by K. Murali Mohan Rao et al [6]. The oven that been used has an automatic temperature control unit with an operating range 50–300^{0}C. An electronic weighing machine (0.0001 g accuracy) is used to weigh the fibers. The percentage of moisture present per unit weight of each variety of fiber is evaluated. The fiber density is measured by the pycnometric procedure. The experimental results for various fibers are enumerated in Table 2.4.

Table 2.4: Percentage moisture present in the fiber on weight basis at normal atmospheric condition and densities of various fibers

Name of fiber	Percentage moisture present in the fiber at normal atmospheric condition	Density (kg/m3)
Vakka	12.09	810
Date(L)	10.67	990
Date(A)	9.55	960
Bamboo(M)	9.16	910
Bamboo(C)	10.14	890
Palm	12.08	1030
Coconut	11.36	1150
Banana	10.71	1350
Sisal	9.79	1450

2.3 Extraction Process

There are several methods that been practice to extract the banana fibers. The extraction process done by S.M. Sapuan et al. [1], [2] is a manual process. These methods are messy and take long time but it is more cost effective. The extraction method that been used is not practical for big production and for industries usage. However for study purposes, this method is suitable with some adjustment. Figure2.3 shows the basic steps that practiced by S.M.Sapuan. In this method, the fibers were woven meanwhile in this project; the author just let the fibers free flow.

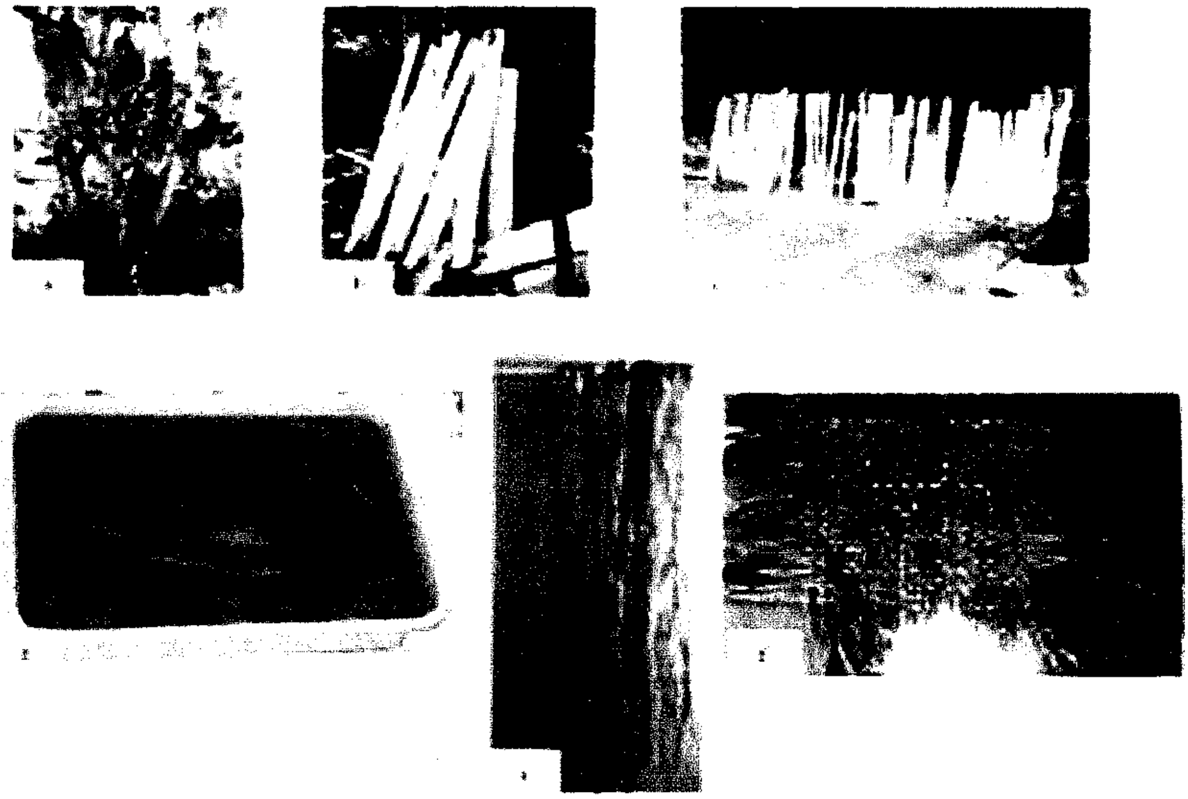


Figure 2.3: Extraction and pre-processing of banana trunk fibers (a) banana trees (b and c) Drying process of banana pseudo stems (d and e) loose fibers (f) woven fabric of banana stem fibers. [2]

There is another method that been applied with a simple technology had been evolved, earlier at All India Khadi & Village Industries Association (Wardha), and later on at CSV, Wardha. It was further improved at Dharamitra. [21], [22] and the improved steps are as follows;

1. Chopped the banana stems into small pieces of 3-4” size

2. Soaked the chopped stems in 1-2% NaOH for 2hours. The alkali loosens the ligno-cellulosic bonds, thereby softening the material.

3. The softened material is transferred to bamboo baskets and washed with water to remove the black liquor of sodium lignite and unused alkali.

4. The washed material is then subjected to beating in a Hollander beater. This is followed by a wet beating. In this process, internal fibrillation of the fibers takes place. A period of three to four hours of beating is required for a getting good quality pulp.

H.A. Al-Qureshi et al. has improve further the method to extract the banana fibers where much suitable for the use of banana fiber reinforced composites for development of a truck body. [3] The extraction process of the natural fiber from the plant required certain care to avoid damage.

Previously, the banana needs to be rolled lightly to remove the excess moisture. Impurities in the rolled fibers such as pigments, broken fibers, coating of cellulose etc. were removed manually by means of a comb. This mechanical and manual extraction of banana fibers was tedious, time consuming, and caused damage to the fibers. Consequently, this type of technique cannot be recommended for industrial application. A special machine was designed and developed for the extraction of banana fibers in a mechanically automated manner.

It consists mainly of two horizontal beams whereby a carriage with an attached and specially designed comb, it could move back and forth, Figure 2.4. The fiber extraction using this technique could be performed simply by placing a cleaned part of the banana stem on the fixed platform of the machine, and clamped at the ends by jaws, Figure 2.4. This eliminated relative movement of the stem and avoided premature breakage of the fibers. This was followed by cleaning and drying of the fibers in a chamber at 20^0C for three hours.

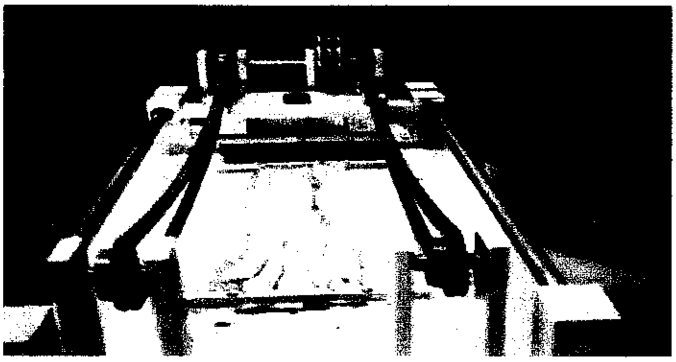


Figure 2.4: Banana Fiber Extracting Machine [3]

2.4 Application of banana fiber composite

H.A. Al-Qureshi et al. have study about the use of banana fiber reinforced composites for the development of a prototype truck body called "Manaca".[3] The development of these application was drive by the demands of these industries are weight reduction and thereby fuel economy. Nevertheless, there is a gap where relatively cheaper composites can be employed, particularly in applications where extended applied loads are not severe. Result of this study was excellent and the bondings between the fibers were observed, whether synthetic or natural in polymeric matrix, were excellent and showed no sign of delamination or debonding. The "Manaca" has been exposed to all types of weather conditions except snow and freezing temperatures, and has been monitored for fatigue and crack initiation. The truck weight is about 850kg and the author believed that it can be reduced more than that. But the automotive application, certainly high speed manufacturing process to meet industrial demand is a need.

S.M.Sapuan et al. was developed a household telephone stand by natural woven fabric reinforce epoxy grade 3554 A and hardener 3554 B composite and multipurpose table. The studies explain about the usage and steps to design and fabricate the home applications natural fiber composite. [1], [2]

Others application of the banana fibers are:

- Banana fiber as a natural solvent
- Banana fiber as a base material for bioremediation and recycling
- Banana fiber as a natural water purifier
- Banana fiber as a base material for the paper and pulp industry
- Banana fiber in the mushroom industry
- Banana fiber in handicrafts and textiles
- Banana fiber a license to print money

2.5 Resin

The resin is an important constituent in composites. The two classes of resins are the thermoplastics and thermosets. A thermoplastic resin remains a solid at room temperature. It melts when heated and solidifies when cooled. The long chain polymers do not form strong covalent bond. That is why they do not harden permanently and are undesirable for structural application. Conversely, a thermoset resin will harden permanently by irreversible cross-linking at elevated temperatures. This characteristic makes the thermoset resin composites very desirable for structural applications. The most common resins used in composites are the unsaturated polyesters, epoxies, and vinyl esters; the least common ones are the polyurethanes and phenolics.[4]

2.5.1 Epoxy

Epoxy resins are a large family of resins that represent some of the high-performance resins available in market. They are generally two-part systems consisting of an epoxy resin and a hardener which is either amine or anhydride.

Starting materials for epoxy matrix are low-molecular-weight organic liquid resins containing a number of epoxide groups, which are three-membered rings of an oxygen atom and two carbon atoms:

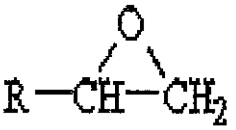


Figure 2.5: Molecule structure of epoxy resin

A common starting material is diglycidyl ether of bisphenol-A (DGEBA) that is a typical commercial epoxy resin and is synthesized by reacting bisphenol-A with epichlorohydrin in presence of a basic catalyst.

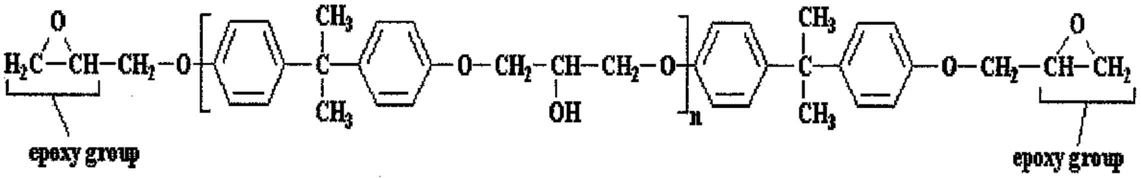
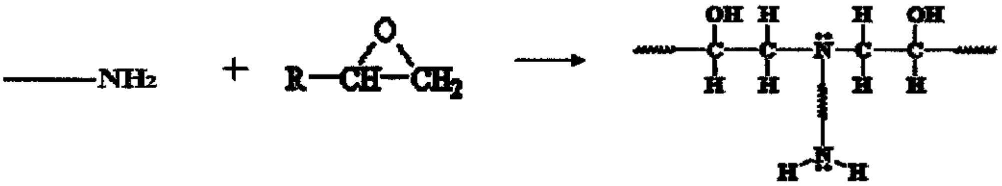


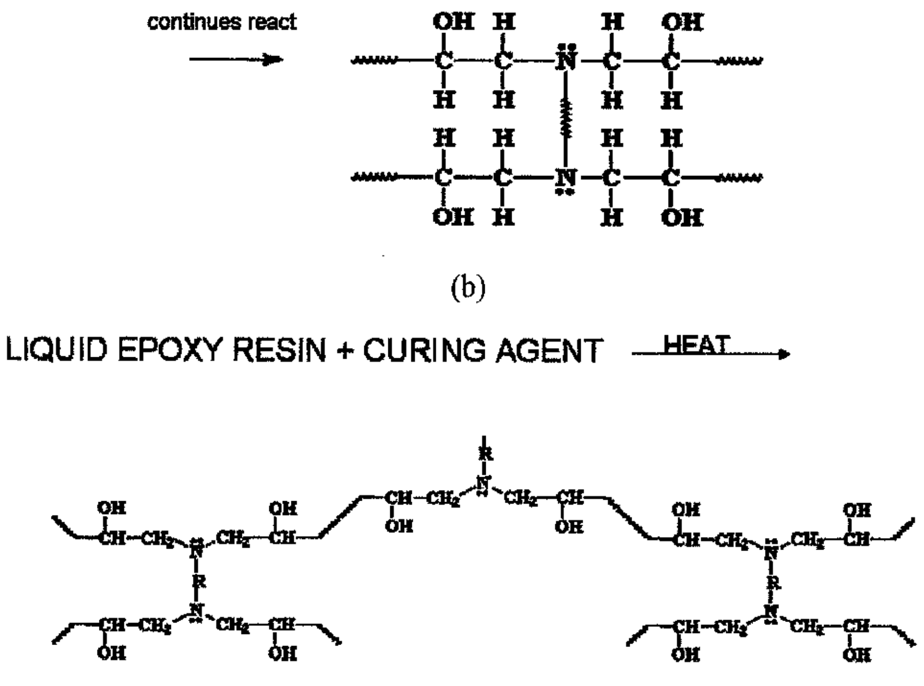
Figure 2.6: Structure of DGEBA

The properties of the DGEBA resins depend on the value of n, which is the number of repeating units commonly known as degree of polymerisation .The number of repeating units depend on the stoichiometry of synthesis reaction. Typically, n ranges from 0 to 25 in many commercial products. The polymerization (curing) reaction to transform liquid resin to the solid state is initiated by adding small amounts of a reactive curing agent just prior to incorporating fibers into the liquid mixture. In this project, the curing agent is aliphatic diamine. Hydrogen atoms in the amine (NH2) groups of an aliphatic diamine molecule react with the epoxide groups of DGEBA molecules in the manner illustrated in figure 2.7a. As the reaction continues, DGEBA molecule will form cross-links with each other (figure 2.7b) and the three dimensional network structure is slowly formed (figure 2.7c). The result is a solid epoxy resin.

These resins have excellent environmental and chemical resistance and superior resistance to "hot-wet" conditions. Compare to polyesters, epoxies require more careful processing and more expensive than vinylesters.[4] However, epoxies have better mechanical properties that give better performance at elevated temperature and exhibit a much lower degree of shrinkage (2 to 3%). The outcome of this project shall give a better understanding on the epoxy properties and performance as well as gives a reliable guideline on the epoxy application.



(a)



(b)

(c)

Figure 2.7: Schematic representation of a cross-linked epoxy resin. (a) Reaction of epoxide group with mXDA molecule; (b) formation of cross-links; (c) 3D network structure of solid epoxy

2.5.2 Aliphatic diamine Group

Aliphatic amines have unique properties which make it different form conventional aliphatic diamines group or aromatic amines group. This type of hardener is normally used in ambient temperature; especially lower temperature cure epoxy resin system. The MSDA for aliphatic diamine is at appendix D.

2.6 Gypsum powder

Gypsum is a common naturally occurring crystalline mineral found in sedimentary rock formation. It also produced as a by product of several industrial and manufacturing process which is flue-gas desulphurization of fossil fuel powered electrical generating plants, sometimes referred to as "synthetic gypsum." Both forms of gypsum are chemically the same – calcium sulfate dehydrate ($CaSO4.2H2O$). Gypsum board is produced by combining calcined gypsum with water and other additives to form slurry that is fed between continuous layers of paper on a board machine. [24]

2.7 Calculation ratio of banana fiber, matrix and gypsum

The composite will be categorized by the banana fibers, matrix and gypsum ratio. From the MSDS the ratio between resin and hardener is 100:20 by weight. The mold is a rectangular shape with dimension of 14cm x 14cm x 0.4cm which is 58.80cm^3. The ratio of 10 volume % of fiber is basically 10 volume % of fiber from the volume of mold which will be 5.88cm^3 same goes to volume % of matrix and gypsum. Detail calculation will be provided at appendix B and table 2.5 shows the weight of banana fiber, epoxy, hardener and gypsum powder that will be mixed tin preparing a composite at difference ratio.

Table 2.5: Weight ratio of epoxy resin, hardener and banana fibers

58.8	vol	mass fiber		vol matrix	mass matrix	weight epoxy	weight amine		vol	mass gypsum
30%	17.64	2.62	70%	41.16	46.10	34.92	11.18	0	0	0
40%	23.52	3.49	60%	35.28	39.51	29.93	9.58	0	0	0
50%	29.4	4.37	50%	29.40	32.93	24.95	7.98	0	0	0
60%	35.28	5.24	40%	23.52	26.34	19.96	6.39	0	0	0

58.8	vol	mass fiber		vol matrix	mass matrix	weight epoxy	weight amine		vol	mass gypsum
30%	17.64	2.62	60%	35.28	39.51	29.93	9.58	10%	5.88	17.05
40%	23.52	3.49	50%	29.40	32.93	24.95	7.98	10%	5.88	17.05
50%	29.40	4.37	40%	23.52	26.34	19.96	6.39	10%	5.88	17.05
60%	35.28	5.24	30%	17.64	19.76	14.97	4.79	10%	5.88	17.05

58.8	vol	mass fiber		vol matrix	mass matrix	weight epoxy	weight amine		vol	mass gypsum
30%	17.64	2.62	50%	29.40	32.93	24.95	7.98	20%	11.76	34.10
40%	23.52	3.49	40%	23.52	26.34	19.96	6.39	20%	11.76	34.10
50%	29.40	4.37	30%	17.64	19.76	14.97	4.79	20%	11.76	34.10
60%	35.28	5.24	20%	11.76	13.17	9.98	3.19	20%	11.76	34.10

2.8 Flexural tests

The three points bending flexural test provides values for the modulus of elasticity in bending E_B, flexural stress σf, flexural strain εf and the flexural stress-strain response of the material. The Flexural test measures the force required to bend a beam under 3 point loading conditions. The data is often used to select materials for parts that will support loads without flexing.

Flexural modulus is used as an indication of a material's stiffness when flexed. The main advantage of a three point flexural test is the ease of the specimen preparation and testing. However, this method has also some disadvantages: the results of the testing method are sensitive to specimen and loading geometry and strain rate.

$$\sigma = \frac{3FL}{2bd^2}$$

Where;

F = Load (force) at the fracture point
L = Length of the support span
b = Width
d = Thickness

Below is the diagram of flexural test is being done.

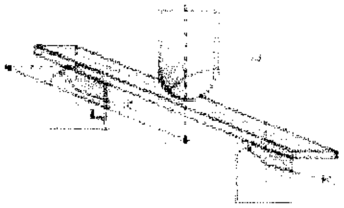


Figure 2.8: Three point testing

2.9 Universal testing machine

The Universal testing test is the most widespread and the most studied mechanical test for composite. The popularity of this test method is explained mainly by the ease of processing and analysis of the test results. The characteristics obtained from Universal testing tests are used both for material specifications and for estimation of load-carrying capacity. Several researches have been carried out in order to characterize the composite materials. The universal testing machine pulls the sample from both ends and measures the force required to pull the specimen apart and how much the sample stretches before breaking.

Figure 2.9: Universal testing machine

CHAPTER 3

METHODOLOGY

3.1 Methodology chart

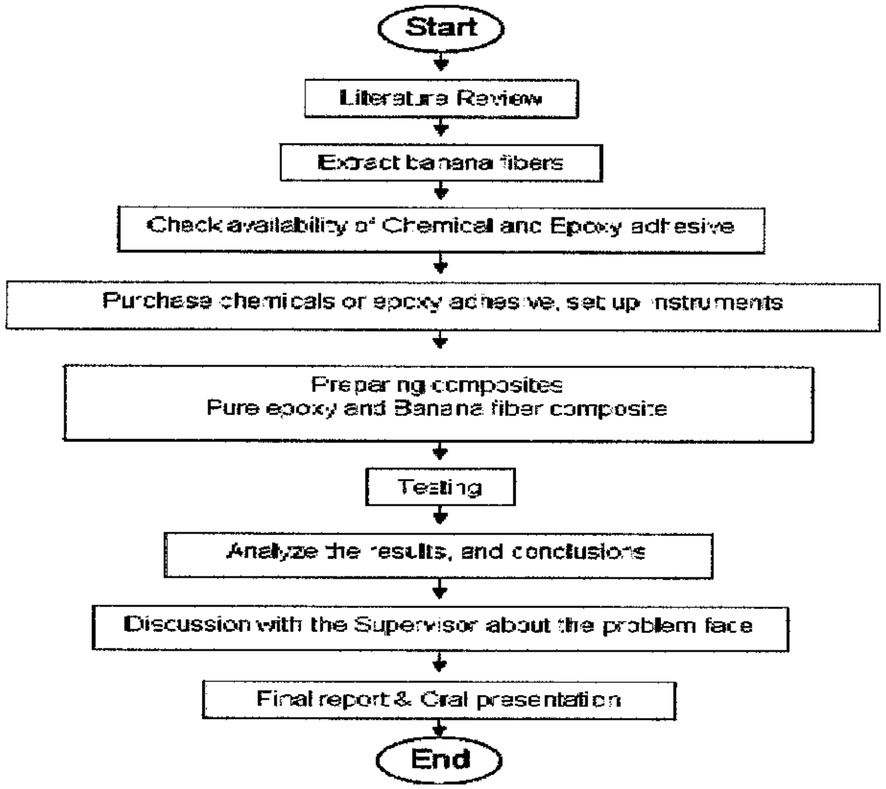


Figure 3.1: Methodology chart

Through out this experiment, 5 types of sample were prepared based on the ratio of fiber, matrix and gypsum added and 1 sample purely matrix as reference (figure 3.2). Different volume percent (vol %) of fiber, matrix and gypsum will result in different flexural strength. Thus, the objective is to find the optimum fiber content that can be added to minimize the usage of matrix with contribute to high flexural strength.

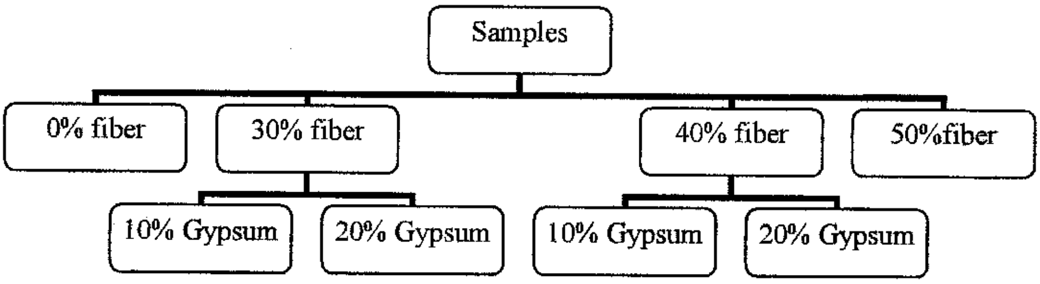


Figure 3.2: Samples to be prepared

3.2 SWOT analysis

SWOT Analysis is a strategic planning method used to evaluate the **Strengths, Weaknesses, Opportunities,** and **Threats** involved in a project. The analysis is done in the beginning of the project to ensure and see the potential of this project. The aim of SWOT analysis is to identify the key internal and external factors that are important to achieving the objective.

Strength is been evaluated based on the attribute that helpful. Weaknesses are the attributes that is harmful or disadvantage for this project to proceed. Opportunities are the external conditions that are helpful to achieving it. Meanwhile, threats are the external conditions which could do damage the opportunities of this project.

Table 3.1: SWOT analysis

Strengths	**Weaknesses**
♦ 2nd most widely cultivated fruit in Malaysia and 21st rank of the exports banana fruits in the world	♦ Not much expertise as yet in Malaysia for banana fiber extraction
♦ By-product of banana fruit cultivation (can get cheap)	♦ No patent held by Malaysia on banana fiber
Opportunities	**Threats**
♦ Mainly use the fruit and ignore the trunk/ stem	♦ Decreased banana production
♦ Existing local market	♦ Increasing threat of diseases (particularly Fusarium wilt)
	♦ Marketing issues (Malaysia just produce as food)

3.3 Materials and chemicals

1. Banana fiber
2. EPOLAM 2050
3. Hardener
4. Gypsum powder
5. Wax (releasing agent)

3.4 Equipments required

1. Disposable Nitrile gloves
2. Safety glasses
3. Clean paper cup container
4. Wooden stir stick
5. Weigh scale
6. Universal testing machine
7. MSDS
8. Oven
9. Mold

3.5 Physical pseudo-stem banana

The knowledge about banana plant is a need in order to enhance and fasten the progress. Several banana plantations in Bota and Setiawan have been identified to be the base case study for this project. On 10th August 2008, an interviewed [17] and researched have been done. Base on the short interviewed with the banana plantation's farmer; the banana pseudo stems were thrown and left at the field and some of the wastes were burned.

The physical properties such as the diameter, height, weight and circumference of the banana tree need to be determined and the steps are follows:

1. 2 types of banana trees were identified
2. Set the measuring apparatus
    - 10kg weighting scale

- 30cm ruler
- measuring tape

3. The height of the individual banana tree were estimated
4. The banana trunk was cut into sections. Whereas each section will have a gap about 30cm
5. The circumference and diameter for each section were measured and recorded.
6. The thickness of each layer for each section was measured and recoded the numbers of sheath.
7. The banana trunk sections were weighed
8. Peeled the layer of banana trunk and weighed each layer.
9. The strength distribution were determine
10. Take samples of the sheath and proceed with the extracting the fiber.

The result of this researched were simplified in the appendix A.

3.6 Pseudo-stem banana fiber extraction

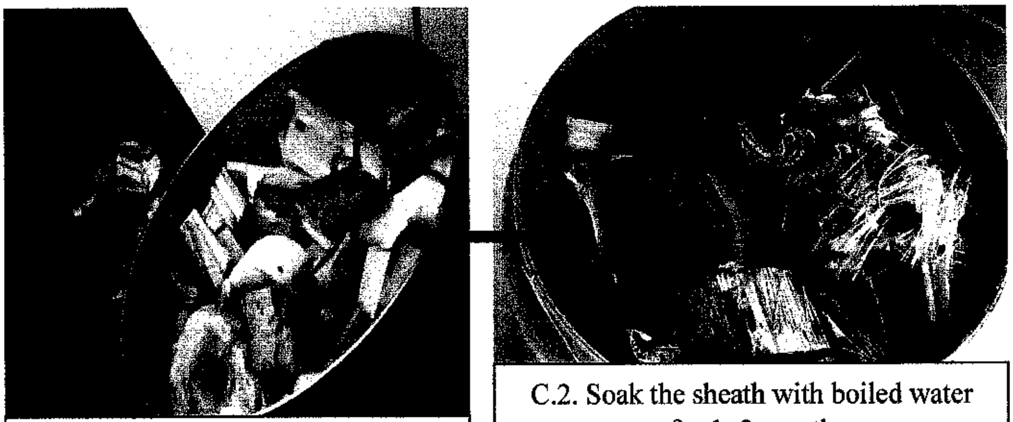
The technology used to extract fiber from the banana trunks is as been practice at Koperasi Usahawan Kampung Balik Pulau (KUKAM) with some modification by the author. The extraction processes are as follow:-

1. Cut-off the banana trunks and chopped 2inches wide.
2. Remove the inner sheath (less fiber content)
3. Boil all the sheaths with water for about 3hours
4. Blend the sheaths with special blender for 15minutes.
5. Transfer to basket and wash with water.
6. Dried inside oven at 60 °C.
7. Grind the fibers to 5mm long.

The boiled water (no.3) can be reuse to soften the sheaths by soaking into the reuse water for about a month or two. After that, repeat step 4 to step 6. This method can save the fuel gas usage for boiling water but it takes time.

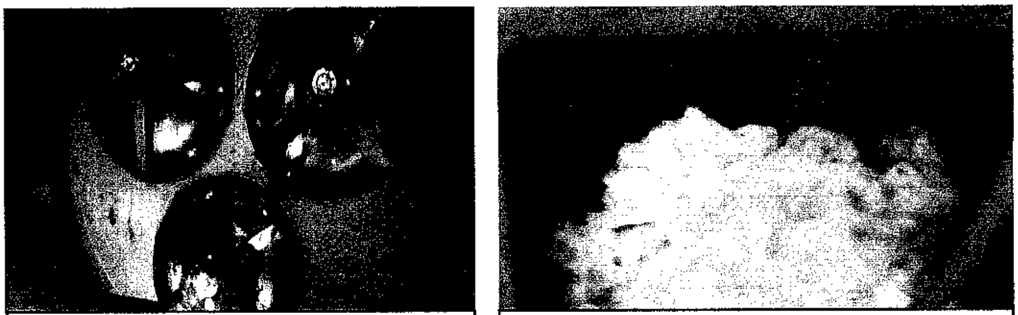
A. KUKAM building in Penang

B. Banana trunks were chopped ~2inches



C.1. Boiled the sheath to ~3 hours

C.2. Soak the sheath with boiled water for 1~2 month



D. Special blender to produce the fibers

E. Wash the fibers with plenty of water to remove ashes

Figure 3.3: Pseudo-stem banana fiber extraction processes

3.7 Composite preparation

The methods of preparation of specimen are simplified here by the following points:

1. Read all safety instructions indicated on the safety data sheet for the product.
2. Prepare all working surfaces and/or tooling for the application.
3. Place the paper cup container on the scale and tar.
4. Pour the epoxy resin into the cup and accurately weigh the required amount of epoxy according to the mixed ratio. (Refer section 2.7).
5. Tar the scale again
6. Add the required amount of hardener solution according to the mix ratio. (Refer section 2.7).
7. Scraping the sides of the paper cup container to make hardener evenly dispersed in the resin. The epoxy and hardener is thoroughly mixed together.
8. Stir the mixture using wooden stick to maximize air entrapment due to turbulent in the material for about 3 minutes.
9. Well clean and dry the mould. Lay up releasing agent on the mould
10. Mix the desired banana fiber with the matrix.
11. Laid up uniformly the mixture into the mould (figure3.4).
12. Close the mould and press the composite material uniformly for 24 hours for curing.
13. Detach the composite from the mould after the composite fibers are fully dry.
14. Cure the composite at 60°C for 1hour and increase to 120°C for 2hours.
15. Measure the density of the composite produce.
16. Cut the composite fibers to specimen sizes ready for testing
17. Repeat the procedures according to different fiber, matrix and gypsum ratio.

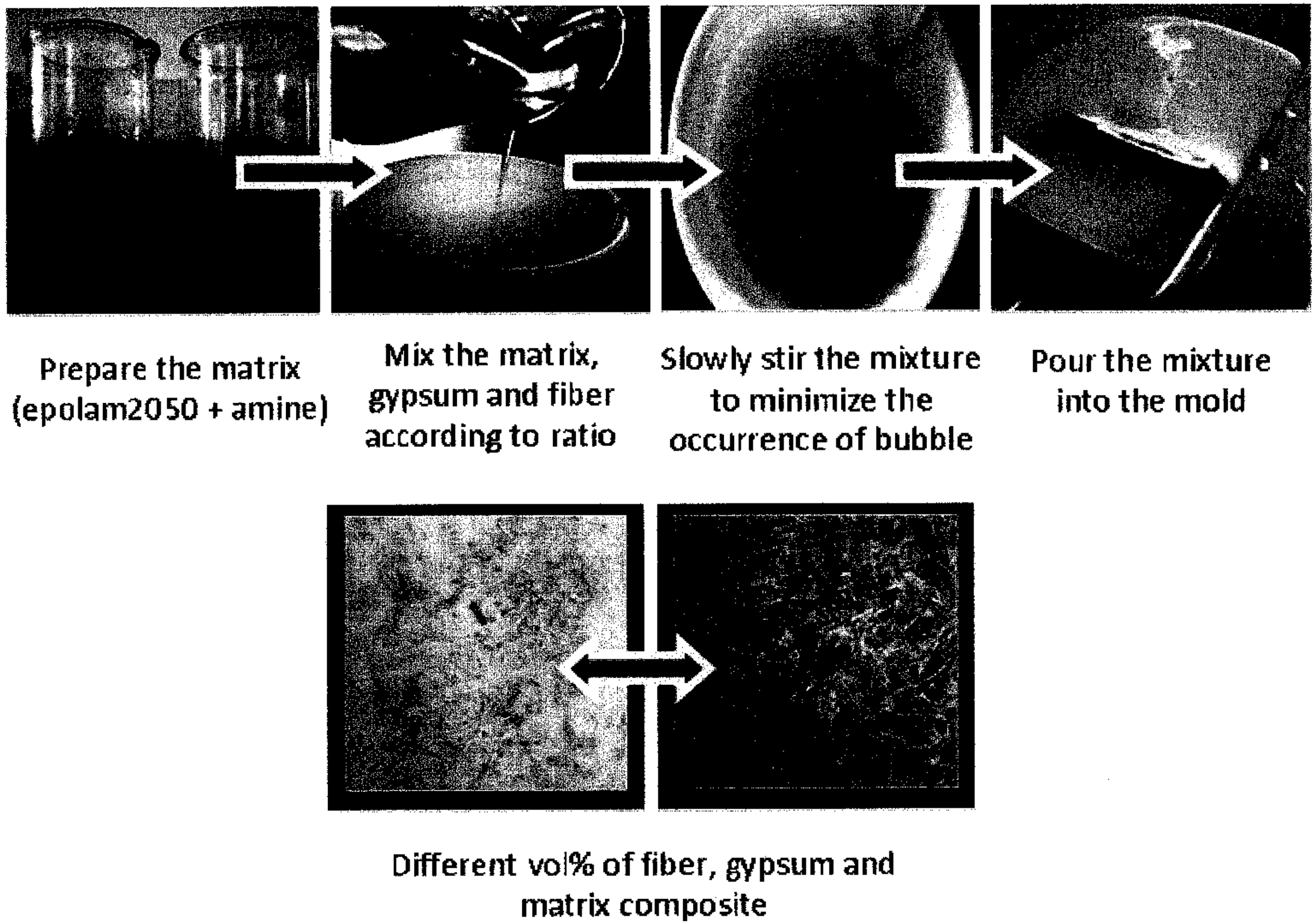


Figure 3.4: Composites preparation

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Physical properties of banana

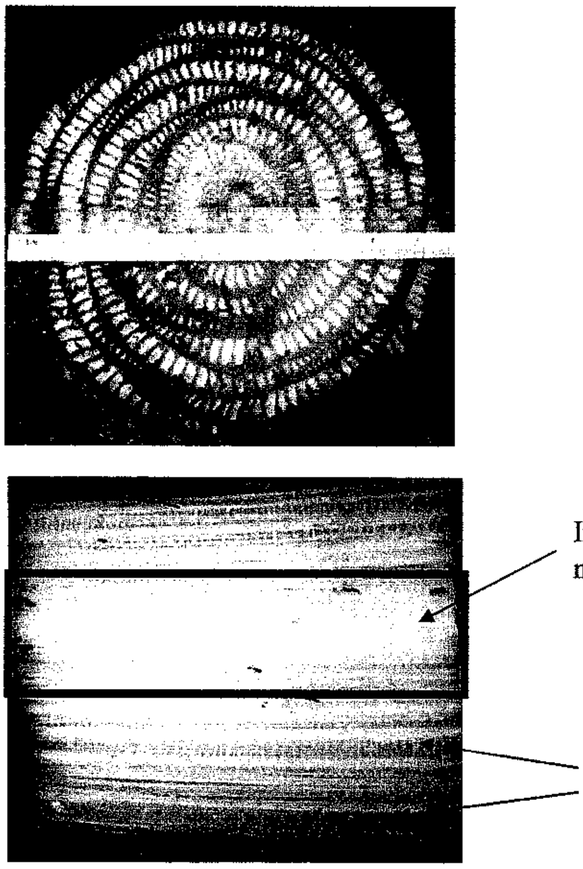
The banana type that will be used for this project is known as Pisang Abu (*Musa acuminata Colla (AAA Group)* cv. 'Dwarf Cavendish'). One of the factors is the easiness and availability to get the sources near the campus. The physical properties of two types of banana trees has been observed and measured as tabulated in table A.1 and A.2 at appendix A.

Diameter and circumference of Pisang Abu trunk is much bigger than Pisang Rastali. In contras, Pisang Rastali can grow taller than Pisang Abu which is 5.7m, 4.3m. As a result, Pisang Rastali can have longer fibers than Pisang Abu due to the different sheath length. However the Pisang Abu has more sheaths which are 27 sheaths and bigger than Pisang Rastali which is 12 sheaths, hence the diameter and circumference is bigger. The sheaths were taken out and calculated as in figure B.i in appendix B. Since the Pisang Abu's sheaths is bigger and few, we can extract more fibers from it. In addition, the banana source of Pisang Abu tree is higher than Pisang Rastali tree in Universiti Teknologi PETRONAS area.

Table 4.1: Physical properties of banana plant

Types	Pisang Abu	Pisang Rastali
Height, m	4.3	5.7
Sheath	27	12
Diameter, m	0.27	0.23

The outer layer of the banana trunk content short fiber and the second and third outer layer consist of long fiber. Meanwhile, fiber from the core of the trunk cannot be extract since the inner part is hard and solid.



Inner layer that content minimum of fiber

Sheaths content high fiber

Figure 4.1: Cross-sectional area of banana trunk

4.2 Banana fiber

Two bottom sections of Pisang Abu were extracted initially. From these two sections about 0.5kg of fiber was produce. The density of the fibers is 0.1485 g/cm^3 where measured by using Utrapycnometer 1000 at 33.4 ^{0}C.

The same type of banana was extracted later at KUKAM by using their existing technology (section 3.6). The fiber that been extracted were nearly 3%-5% of wet weight of the trunk. In other words, approximately 2.5kg of fiber (maximum) will be produced from each banana trunk that has 50kg of wet weight equivalent to 1 banana tree.

Figure 4.2: Extracted banana fiber

4.3 Composites

The difference of fiber–gypsum ratio and fiber size definitely affect the individual strength of the composite.

4.3.1 Length of fiber

In determining the effect in length of fiber, two different length were used which is 50±5mm for long fiber and 5±5mm for short fiber. The fibers were mixed with the matrix according to its ratio (0, 30, 40vol %).

The composite with long and short fibers distribution are not same where the concentration of fibers accumulated is evenly distributed in short fiber and not evenly distribute in long fiber. This is because the long fiber may entangle each other. The distribution of fibers will affect the strength of the composite. If the distribution is not even, the area that have little amount of fibers or not been covered by fibers will become weak compared to area with fibers.

Figure 4.3: Vacant space due to unevenly fibers distribution

The flexural strength of composite is different between the short and long fiber. As the fibers ratio increase in long and short fiber, the flexural strength is increasing but decrease after exceeding 60vol % due to limitation of matrix to coat the overall fibers (figure 4.8). Figure 4.4 show the flexural strength of different volume % of banana fiber/epoxy for short and long fiber. At 30vol% of long fiber exhibit more flexural strength than in 40vol% which is 47MPa and 65MPa. Meanwhile, in short fiber, 40vol% of fiber also exhibit the highest flexural strength compare to 30vol%, 73MPa and 65MPa.

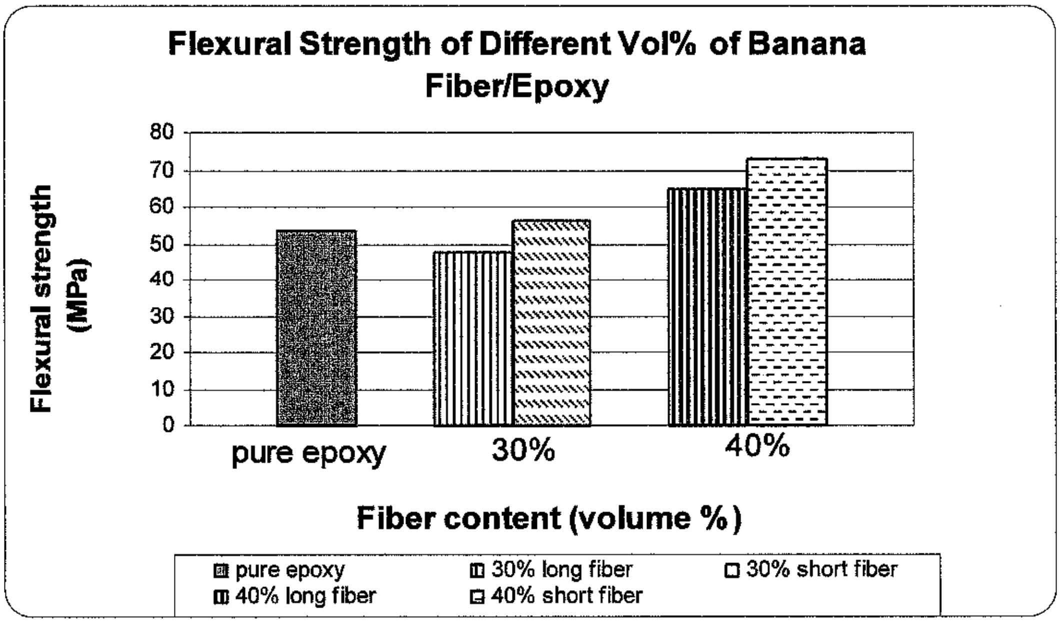


Figure 4.4: Flexural strength of different volume % of banana fiber/epoxy

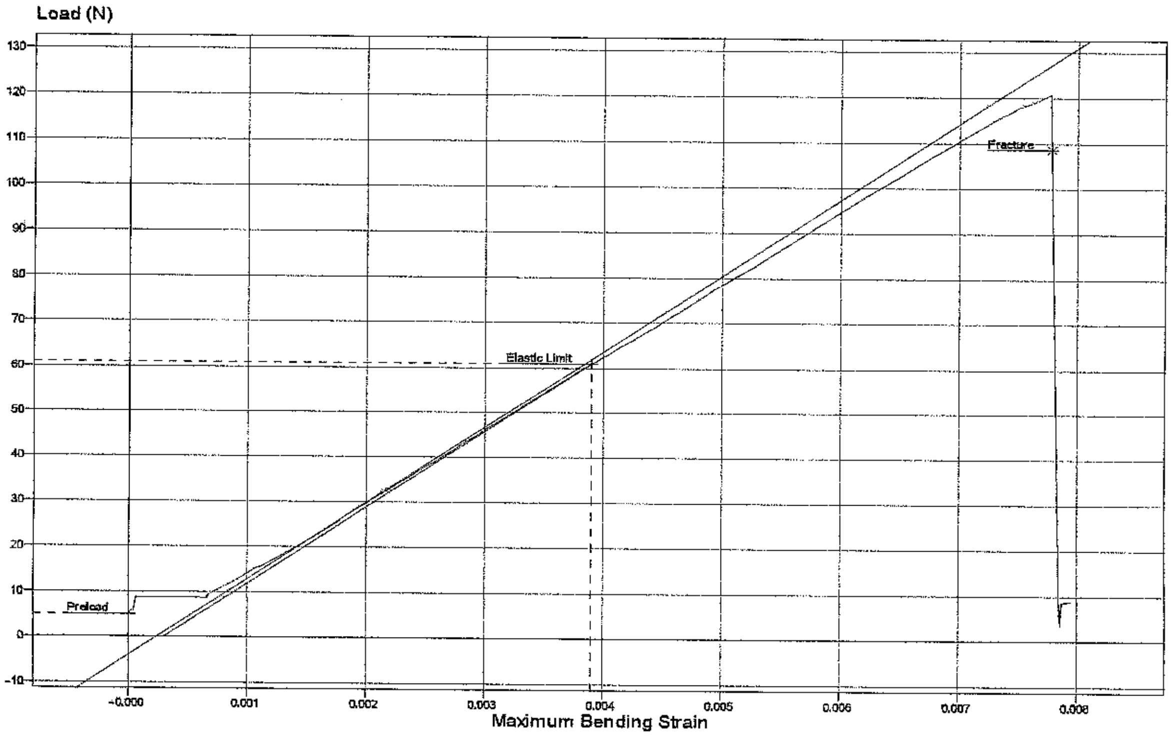


Figure 4.5: Graph of load vs. maximum bending strain of composite at 40vol% of short fiber

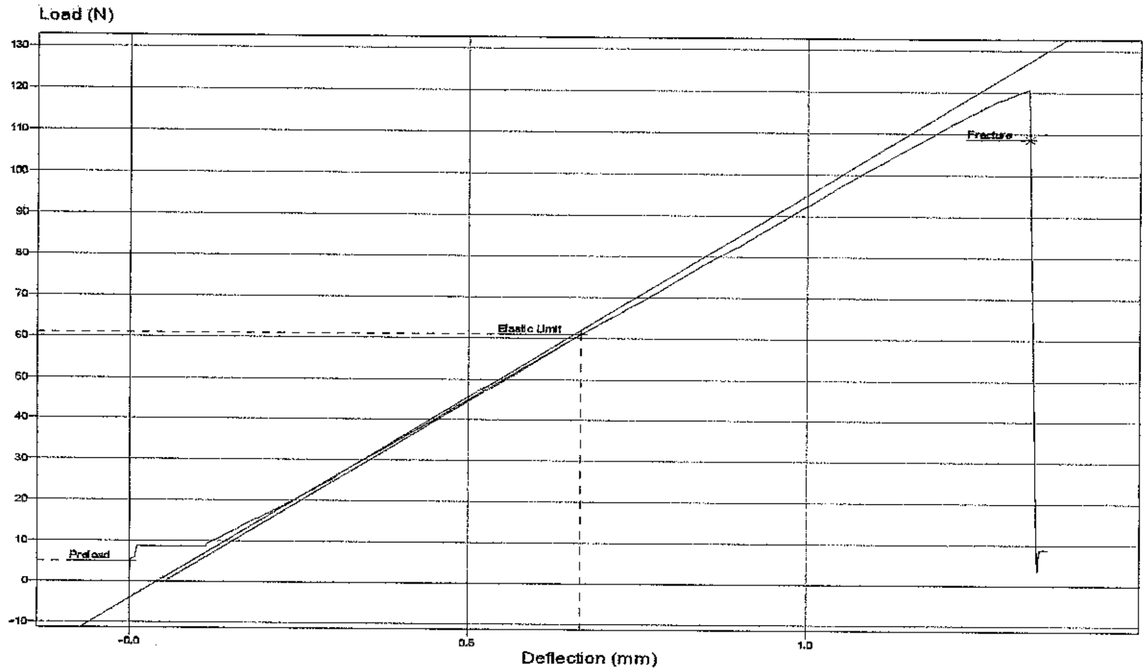


Figure 4.6: Graph of load vs. deflection of composite at 4vol% of short fiber

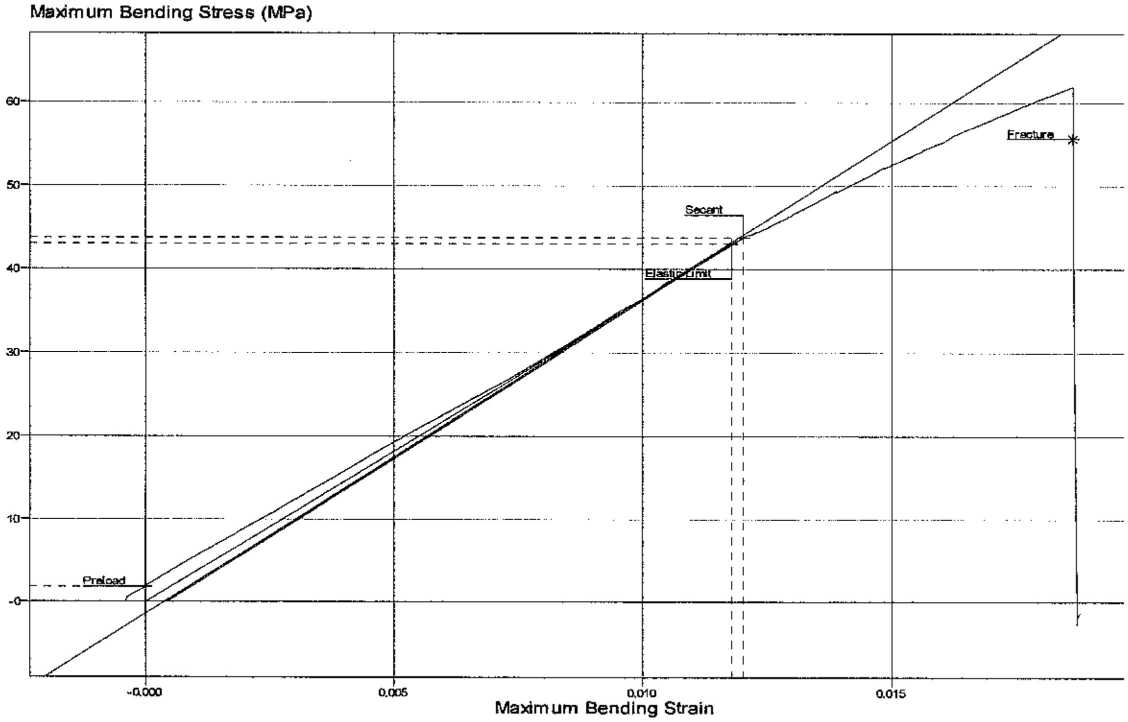


Figure 4.7: Graph of stress vs. strain of composite at 40vol% of short fiber

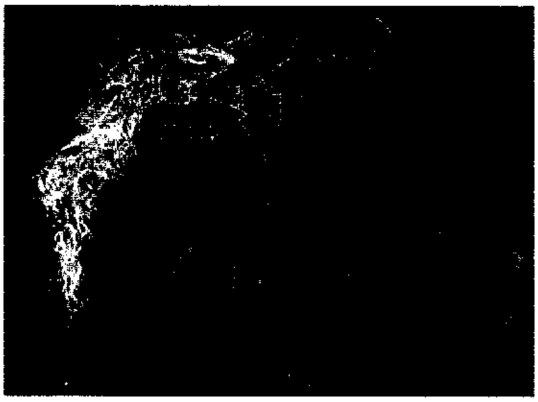


Figure 4.8: Uncoated fiber at more than 60vol% of long fiber

In previous study done by S.M Sapuan, the flexural strength of woven banana reinforced epoxy is 73.58MPa which is higher compared to long fiber in this study. This is due to the fiber distributions where only certain area will be covered by fiber and bubble occurrence.

According to the previous researched, Laly *et al.* [10] have investigated the banana fiber reinforced polyester composites and found that the optimum content of banana fiber is 40vol% in HDPE. S.Mishra *et al.* [10] also found that as the banana volume increase exceeding 40 to 55vol%, the young's modulus, flexural modulus, impact strength and hardness is decreasing. It shows that the optimum fiber content is at that range same goes to this research where the maximum is at 40vol% of fiber.

4.3.2 Banana fiber reinforce epoxy-gypsum

The idea of adding gypsum powder was from the accident of ceiling rupture due to not resist to water absorption. Hence gypsum powder ($CaSO_4.2H_2O$) was added according to the ratio 10vol% and 20vol% of gypsum at 30vol% and 40vol% of short banana fiber and stud. The addition of gypsum into the matrix and fiber make the composite looks so nice and can be commercialize since the color of gypsum is white and it can be colored by adding dye into the gypsum. Figure 4.9 show the effect in color of gypsum adding.

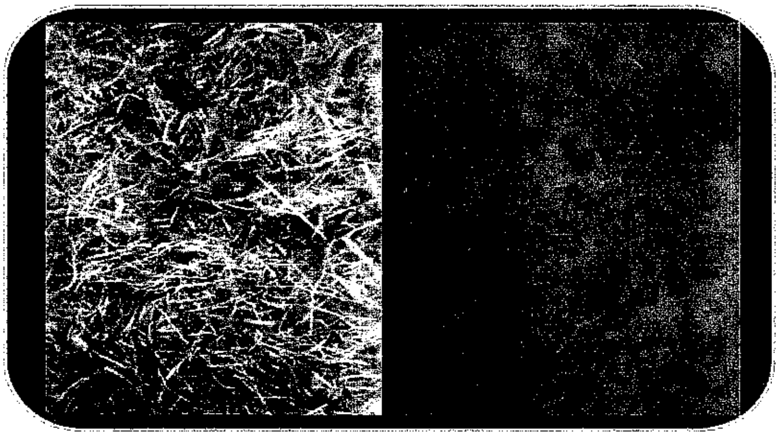


Figure 4.9: Composite without and with adding gypsum

The composite weight of composite was increase after gypsum powder was added according to the volume ratio added. This is because the density of gypsum powder is greater than epoxy and fiber which is 2.9g/cm^3.

In 10vol% of gypsum added, the flexural strength of composite with 40vol% of short fiber is 80MPa with 154N maximum load while the 30vol% of fiber is about 45MPa and 118N maximum load.

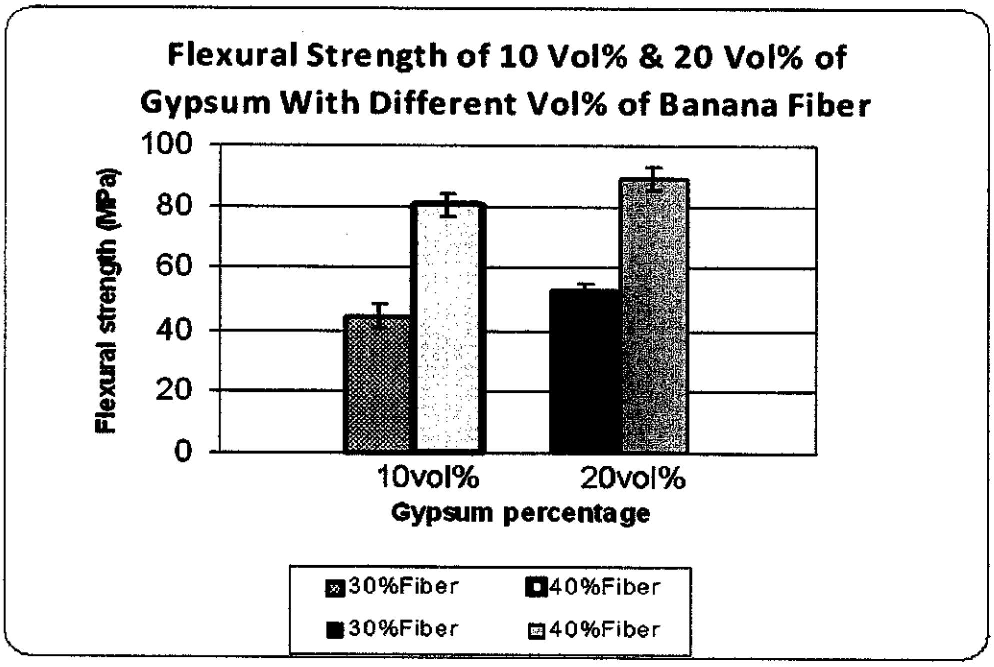


Figure 4.10: Flexural strength of 10vol% and 20vol% of gypsum with different vol% of banana fiber

The flexural strength of those composites was disturbed because the structures of the composite were changed. This is because the composites are already exposed to vibration and impact during cutting for testing sample preparation. This may affect the strength of the composite.

4.3.3 Challenge and lesson learn

Throughout this project, the issue during preparing the composite is the bubbles occurred in the composite due to improper stirring procedure during sample preparation. These bubbles will be the formation of honeycomb at the composite and will be the fracture/ weak point for the composite. There are few solutions to minimize the bubble occurring such as by using special roller and air vacuum. The best way to remove all the bubbles is by using air vacuum.

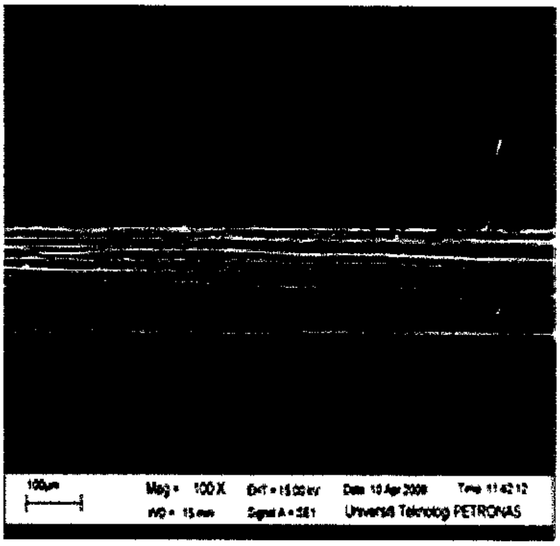
The mixing process of matrix, fiber and gypsum are so important because it will affect the strength of the composite. In order to ensure the matrix perfectly mixed, the author need to pour the hardener followed by the resin due to the different in density where the resin is heavier than hardener. However, by using stirred instrument will make it much easier and time is the only constrain here. After the matrix ready, pour the gypsum and followed by the fiber In addition, the ratio between resin and hardener need to be accurate based on its ratio because it will effecting the Tg (glass temperature) of the composite.

4.4 SEM Test

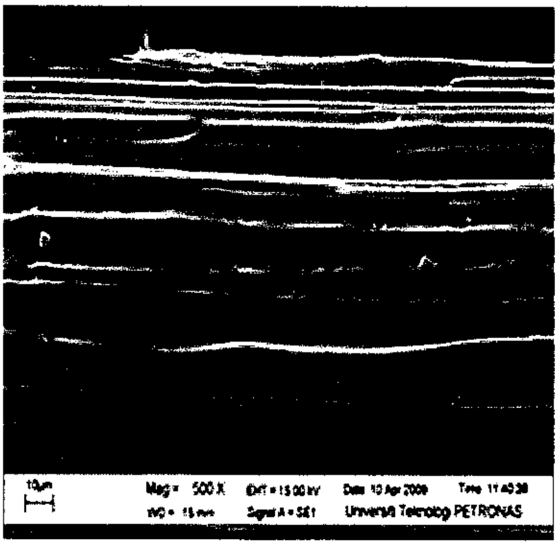
Microscopic level of the sample can be observe through SEM. The purposes of this test were to observe the surface and fracture of the samples. It is observed that there are bubbles can be seen at every surface of the samples. These bubbles occur because of improper mixing. SEM test also show the size and shape of fiber and gypsum.

4.4.1 Raw banana fiber and gypsum

Thickness of the raw fiber from Pisang Abu is 148.5µm. The fiber surface is smooth and straight. Meanwhile the gypsum powder particle size is 2μm^2



a



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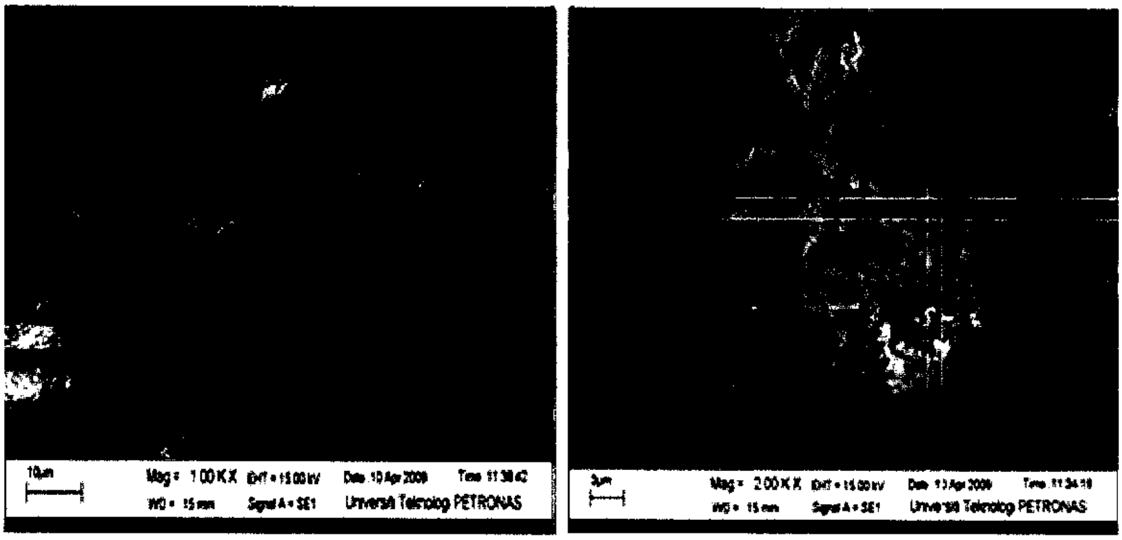
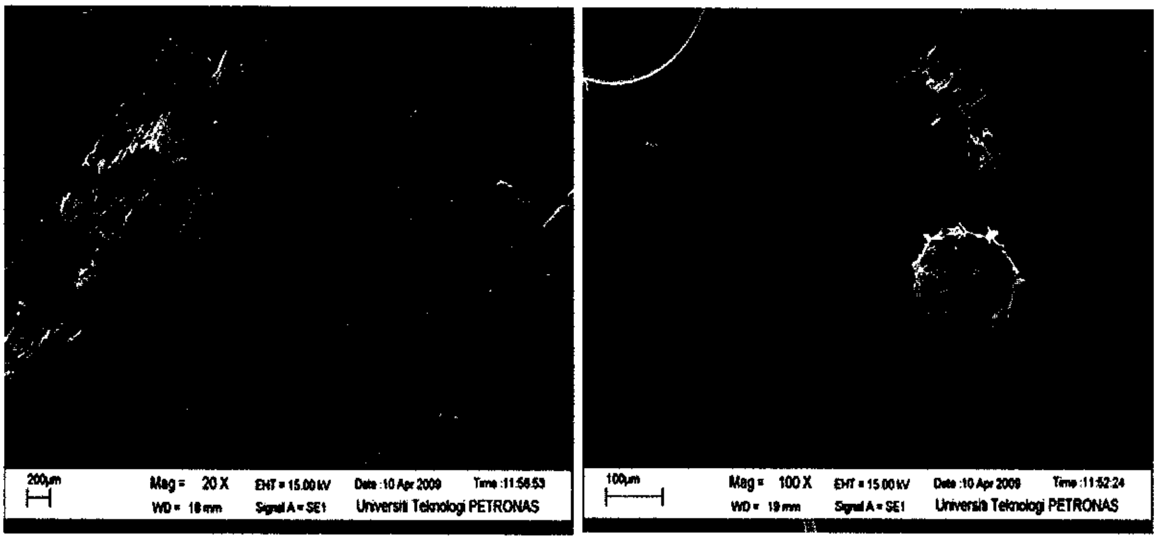


c d

Figure 4.11: SEM for raw banana fiber (a & b) and gypsum particle (c & d)

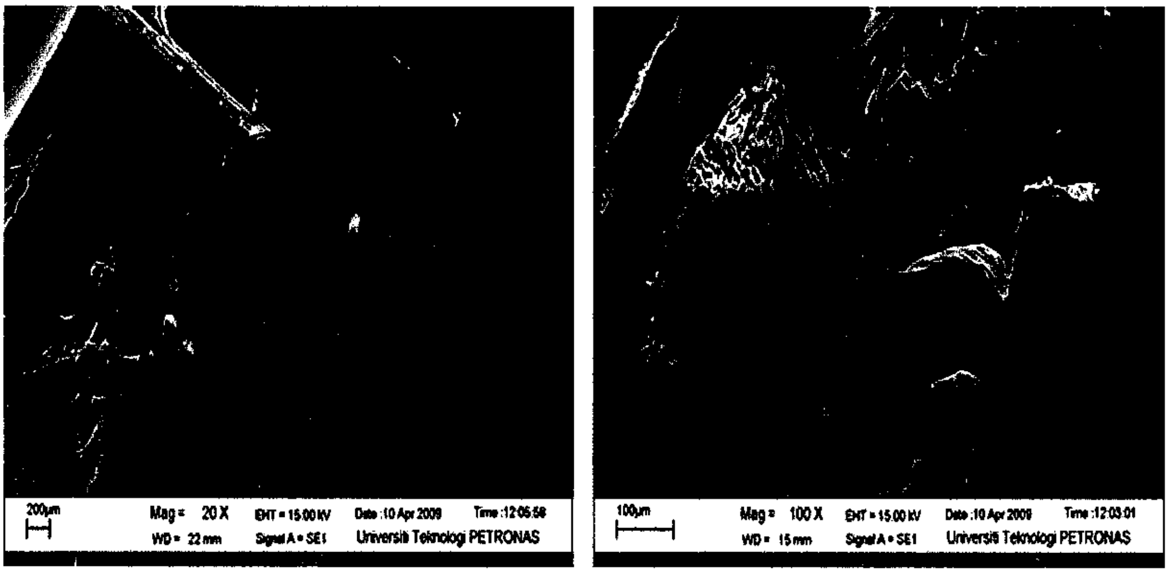
4.4.2 Composite at fracture surface

The composite is brittle base on the fracture surface of those composite. The fiber distribution is not even at the fracture surface. If the fiber align is in unidirectional, 90° or woven, the fiber would be seen so much at the fracture surface. The surface in composite with gypsum added is a bit rough compared to fiber with matrix only.



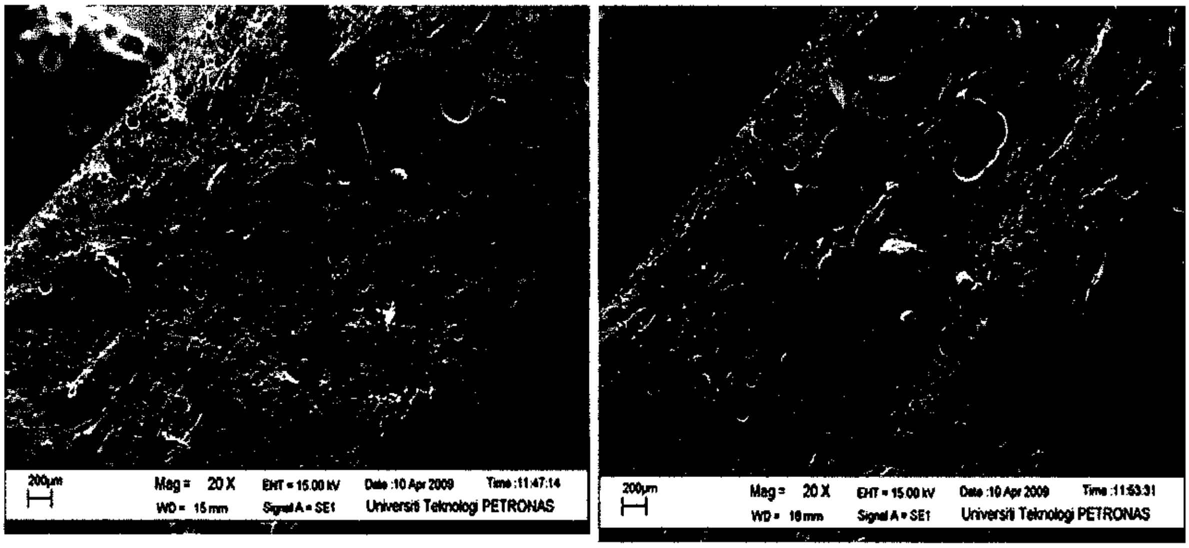
a b

Figure 4.12: SEM for 30vol% and 40vol% of short fiber



a b

Figure 4.13: SEM for 30vol% and 40vol% of long fiber



a b

Figure 4.14: SEM for 30vol% and 40vol% in 10vol% gypsum

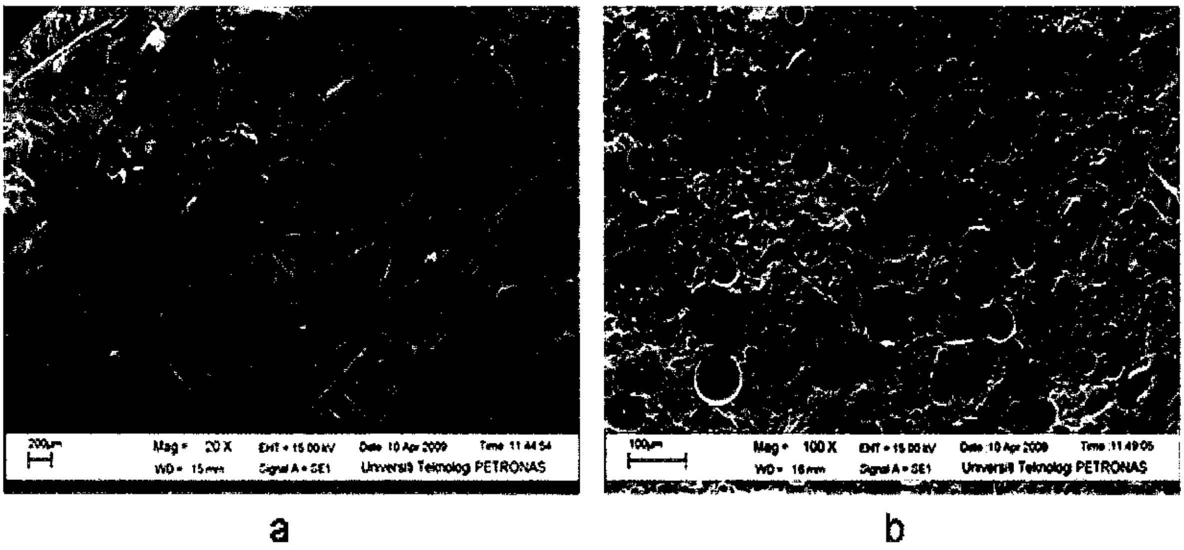


Figure 4.15: SEM for 30vol% and 40vol% in 20vol% gypsum

4.5 Applications

There are so many applications that can be introduce at 40vol% of banana fiber with adding gypsum or without gypsum added such as table top, mosaic, guardrail and ceiling. Those applications are very suitable due to the physical and mechanical properties of the composite.

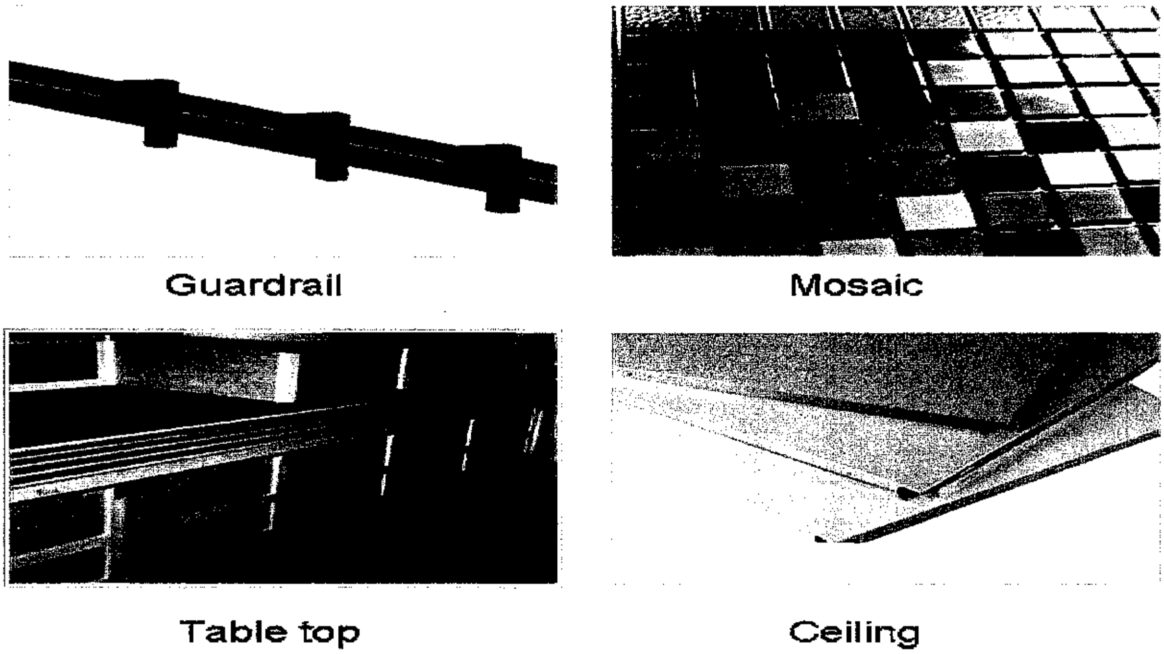


Figure 4.16: Example of banana fiber composite applications

4.6 Economic analysis

The raw materials for the composite are raw banana fiber, gypsum powder, and matrix. Cost for raw banana fiber is about RM 4 per kg [website]. The main raw banana fiber supplier is from India. If the raw banana fiber industry already exists in Malaysia, the raw fiber could be lower than that. Meanwhile the matrix cost is the most expensive among the raw material which is RM 50 per kg. This is the batch price for 20kg of epoxy. The gypsum powder price is expected to be around RM 15 per kg.

Each mosaic tile is 25mm x 25mm over 4.5mm thick. These dimensions are a standard size for glass mosaic tile, which means customer should be able to use these with vitreous tiles from most other manufacturers. The production cost for the composite at 40vol% of fiber at this dimension is **about RM 146.00 per meter square.** This is the economic potential 1 (EP1) which only include the raw materials cost in batch product. However the possibility of these composite production cost reduce is high when in mass production and continuously.

EP 1 = total raw materials cost
= raw banana fiber + matrix (resin + hardener) + gypsum powder

In other application, the price will be different based on the size, shape and ratio. The production cost can be cheaper if the raw material is dominated by the cheapest material like raw banana fiber.

CHAPTER 5
CONCLUSION

5.1 Conclusion

The banana fibers that the author uses were extracted from Pisang Abu (***Musa acuminata Colla (AAA Group)*** **cv. 'Dwarf Cavendish'**). This banana tree is one of the biggest banana tree group planted in Malaysia. Different section of trunk will produce unfamiliar amount of fiber. The sheaths are differing layer by layer where the fiber content at the inner sheath is lesser than outer layer. The more sheath the banana have, the more fiber can be extracted.

The optimum fiber content is at 40vol% of fiber with flexural strength 73MPa and 67MPa for short and long fiber. In additional of gypsum powder at the composite, the flexural strength and maximum load of the composite will be increasing. The maximum load of the composite at 10vol% of gypsum with 40vol% of short fiber is 81MPa and 30vol% is about 44MPa. For 20vol% of gypsum, the flexural strength is 89MPa and 53MPa for 40 and 30vol% fiber. However, the optimum fiber can be varying base on the difference of banana tree types and the method of compression. A compression molding can compact more fiber with matrix into the mold.

Composite with short fiber are more evenly distribute than long fiber composite. As a result, the flexural strength of the short fiber is better than long fiber.

This project clearly proved that the composite exhibits fine physical and good mechanical properties thus it can be use for various useful applications either indoor or outdoor. The gypsum added in the composite make the composite much commercializes instead of increase its strength.

5.2 Recommendations

1. Generally, long fiber composite will have higher flexural strength than short fiber. However, due to the gap of fiber distribution between long and short fiber, the short fiber exhibit more strength than long fiber. Hence, for future research, avoid the fiber concentration only at one point.

2. Extend the ratio of fiber /gypsum by compression with high pressure which is preferable using compression molding. By applying this method, the fiber content can be increase.

3. For further development of this composite, several test need to be done such as:
    a. Chemical effect of the composite surface especially to detergent or chlorine. This is important to know whether the composite is resist to detergent or not.
    b. Water absorption effect is one of the criteria that need to know because it will effect the application of the composite. If the composite is water resist, it may be applied for outdoor vise versa.
    c. The composite need to be coat to make it scratch resistance.

4. Propose to MARDI, FAMA to start cluster industry for banana fiber extraction due to the potential of banana fiber

5. The composites can be commercialized since it has unique pattern and architectural design. Many applications can be done by using this composite such as guardrail, mosaic, table top, ceiling, food container, or children toys since the composite is safe, low density and low manufacturing cost.

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APPENDICES

Appendix A	**: Banana Pseudo stem**
Appendix B	**: Calculation ratio of banana fiber, matrix and gypsum**
Appendix C	**: Economic potential of composite**
Appendix D	**: MSDS**

Appendix A

Table A1: Pisang Abu

Type: Pisang Abu (*Musa acuminata Colla (AAA Group)* cv. 'Dwarf Cavendish')

Height: 4.7m (including the length of banana leaf)

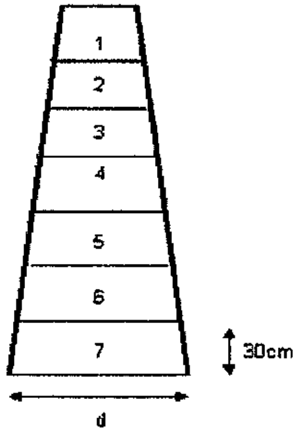
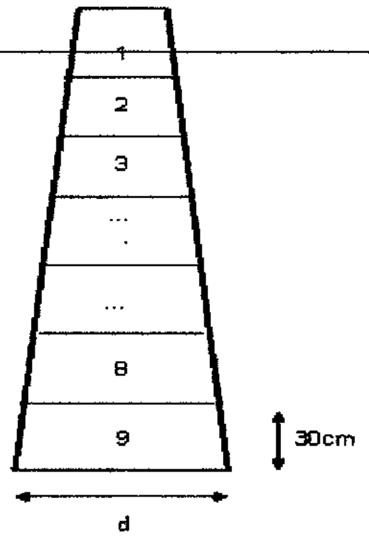
	Weight (kg)	Diameter (cm)	Circumference	
Section 1	3,18	14.4 (top)	48 (top)	
Section 2	3,66	14.5	50	
Section 3	4,15	16.5	53	
Section 4	5,12	18.0	57	
Section 5	5,94	20.0	63	
Section 6	7,53	21.5	70	
Section 7	7,70	25.0	80	
		27.0 (bottom)	86 (bottom)	

Table A2: Pisang Rastali

Type: Pisang Rastali (Musa acuminata x balbisiana Colla (AAB Group) cv. 'Silk')

Height: 5.2m (including the length of banana leaf)

	Weight (kg)	Diameter (cm)	Circumference	
Section 1	2.00	12.00(top)	32(top)	
Section 2	2.30	11.50	39	
Section 3	2.75	12.00	42	
Section 4	3.0	14.00	45	
Section 5	3.3	15	49	
Section 6	3.90	16.5	53	
Section 7	4.5	17.5	57	
Section 8	5.50	19.00	62	
Section 9	7.70	21.0	70	
		23.0(bottom)	76(bottom)	

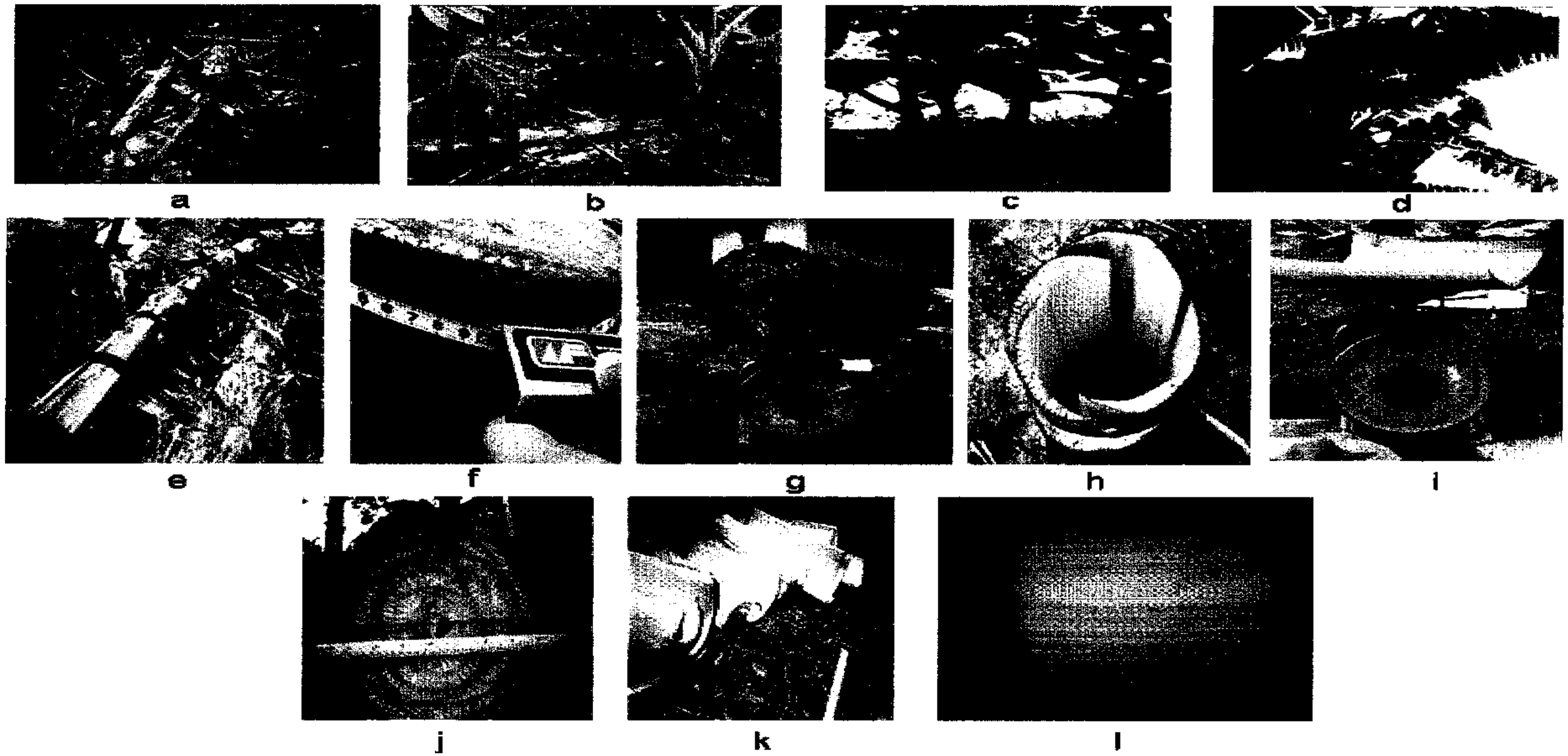


Figure A3 : Research on determining the physical of banana pseudostems (a and b) banana waste (c) *Pisang Abu* (d) P*isang Rastali* (e) banana trunk were cut 30cm each section (f) circumference of the trunk section were measured (g) weigh the trunk section (h) sheaths of the section (i) weigh the sheaths (j) measure the diameter of the trunk section (k) all sheaths in the section were peeled off (l) cross-sectional area of banana trunk.

Appendix B

Calculation ratio of banana fiber, matrix and gypsum

	volume of mold	
height	14	cm
width	14	cm
deep	0.3	cm
	58.8	cm3

density of fiber = 0.1485 g/cm3
density of matrix = 1.12 g/cm4
density of gypsum = 2.9 g/cm5

	fiber	matrix	gypsum
Ratio %	40	50	0

volume of fiber = 40 X 59
= 24 cm3

fiber weight = volume X fiber density
= 3.493 g

matrix volume = 50 X 58.800 / 40
= 73.500 cm3

matrix weight = 73.5 x 1.12
volume matrix density
= 82.320 g

epoxy weight = $\frac{3.125}{4.125}$ x 82.32
= 62.364 g

hardener weight= $\frac{1.000}{4.125}$ x 82.32
= 19.956 g

Gypsum volume = 0 X 58.8
= 0 cm3

Gypsum weight 0 X 2.9
= 0

Appendix C

Economic potential of composite, EP1 calculation

	fiber	matrix	
	4/kg	50/kg	
price/kg	4	50	
vol %	40%	60%	
cm3	1.075	1.6125	
g	0.159638	1.806	
kg	0.00016	0.001806	
price	0.000639	0.0903	0.090939
			7.275084
			145.5017

	fiber	gypsum	matrix	
	4/kg		50/kg	
price/kg	4	20	50	
vol %	40%	10%	50%	
cm3	1.075	0.269	1.344	
g	0.160	0.779	1.505	
kg	0.000159638	0.00077938	0.001505	
price	0.00063855	0.0155875	0.07525	0.091476
				7.318084
				146.3617