Palm Oil Fronds as Alternative Source of Raw Material to Produce Pulp and Paper

by

Mohd Redzuan bin Abu Bakar

Dissertation submitted in partial fulfillment of
the requirement for the
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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,

(Mr. Mohd Faizairi Bin Mohd Nor)

Mohd Faizairi Mohd Nor
Lecturer
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
31750 Tronoh
Perak Darul Ridzuan, Malaysia

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
MAY 2011

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.

MOHD REDZUAN BIN ABU BAKAR

ABSTRACT

This project is about the study of oil palm fronds and its contents in order to make pulp and paper and also paper testing to determine the condition of the paper. Malaysia is the largest producer and exporter of palm oil in the world today, producing about 47% of the world's supply of palm oil and nowadays they are determining to expand the palm oil production capacity since the market demand continues to grow. The growth highlights the potential of using the 26.2 million tonnes of oil palm frond (OPF) for pulp and paper production. Fibers in the palm oil frond (waste) can be transforming into something useful such as pulp and paper instead of burning the waste. To enhance the use of the abundant biomass generated by the palm oil industry in Malaysia, a study was conducted in view of exploring the paper making potential of this industrial by-product. The information about type of oil palm biomass such as empty fruit bunch, oil palm frond and oil palm trunks and their current product was studied in order to ensure that the pulp and paper is a new product for oil palm biomass. The pulp and paper background was studied to get the information about the contents of the paper and the similarity with the oil palm frond that will be used as raw material to make paper. The basic paper making process was studied to get the information on how the paper was made using the current technology. Chemical and physical properties of paper was examined to look at the paper contents and compared with the oil palm fronds to ensure that there are similarity in contents between both components and determine either oil palm frond could be use as raw material in paper making production or not. The physical properties of the paper were determined using paper testing. Due to lack of technology in laboratory, handmade paper making was done using oil palm fronds as raw material. All the paper and oil palm fronds sample was analyze by X-ray Fluorescence (XRF) and Scanning Electron Microscope (SEM) to examine the contents and the structure. The study showed that frond pulp might be used as a raw material in pulp and paper production.

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

Our country is among the leading palm oil producer in the world with the current area planted to grow to about 4.0 million hectares. The Malaysian Government and the private sector to give full support in the palm oil industry through the strategies and policies. Despite the large production, the oil consists of only about 10 % of the total biomass produced on the farm. The remainder of the total oil palm wastes such as palm oil shell, empty fruit bunches and oil palm fronds and large trunks of palm oil. With the following environmental concerns, waste discharged as oil palm frond pulp produced from the biomass used as raw material for paper and packaging, because of various advantages such as light, inexpensiveness, non-toxic and recyclable. Recycling is required for things that are produced that can be used and avoid environmental contamination. Production of pulp from waste paper and oil is the best way as a result of environmental issues today. Used paper can also be recycled to produce new paper for packaging, printing and manufacturing. Availability during the crop stems is calculated using the estimated 10.4 tonnes ha-1, which now provides an average of 6.97 million tonnes per annum. Meanwhile, the average estimated at 54.43 million tonnes per year of palm fronds will be available during the planting process again in the years 2007-2002.

Over the centuries, paper has been another important component of world development, providing a way for people to record and communicate ideas and stories and artwork. Even with the advent of the modern world of plastic bags, electronic communication and paperless office, paper remains the most important materials in houses, factories, offices and schools. Lignocellulosic pulp fibrous material prepared by chemically or mechanically, separating the cellulose fibers from wood fiber crops, or waste paper and agricultural waste. Chemical Pulps made by cooking (digesting) the raw materials, using the Kraft process. Kraft processes produce a variety of pulps are used primarily for packaging and high-strength paper and paperboard. Mechanical pulp can be used without bleach for paper printing to low-brightness applications such as printed paper. Wood pulp is the most common raw material in papermaking. In developing countries, about 60 % of cellulose fibers derived from non-wood raw materials.

Malaysia has a total capacity pulp and paper production at over 1 million T per annum. The country is a net importer of pulp, paper and paperboard, and gradually tends to reduce dependency. However, self-sufficiency level was rising at a slower rate. All paper mills, small country by world industry standards, no issue more than 300 000 T per annum. Pulp and paper industry relies heavily on imported fiber, especially virgin pulp, and also face the need to find a new source of fiber strengthen and maintain the quality of secondary fiber as using recycled paper to grow in Malaysia and further development integration of downstream activities is encouraged. Basically the process of making paper has not changed, despite the high degree of technological advances in the use of machinery and automization was achieved in 150 years. In a dilute suspension of papermaking fibers in the water drained through the screen, so that the mats of woven fibers randomly determined. Water is removed from the mat by pressing and drying the fibers to make paper. Most paper is made from wood pulp, but the resources of other fibers can be used as raw material to make paper.

This project is to study the chemical and physical properties of oil palm fronds and other type of paper to examine the composition in order to make a comparison between both components and determine oil palm fronds as a raw material to make pulp and paper and also paper testing to test the physical properties of the paper samples to analyze their performance.

1.2 Problem statement

In today's world, biomass is a major problem to many countries because of the reasons for the environment. Before the development of technology and studies about oil palm biomass has been reveal, all the biomass only either abandoned at the plantation site or simply be burned and may cause environmental effect such as haze in the air and may give bad condition to peoples. Many studies have been made by some scientists but not all of them can solve the problem of biomass. A lot of biomass waste is used and converted into products of high importance. Oil Palm fronds (OPF) have the potential alternative source of fresh pulp replaced to replace imported fresh pulp. It almost 26.2 million tonnes of oil palm fronds recorded by MARDI in Malaysia. Biomass was the main source of cellulose fiber. This study is important as Malaysia imported a net amount of cellulose is more than RM300 million a year and continues to grow.

1.3 Objectives

The objective of this project is to study the potential of palm oil fronds as alternative source of raw material to produce pulp and paper. The contents of the oil palm fronds and various type of paper need to examine. The physical properties of the paper also need to be determined in order to identify the paper condition.

1.4 Scopes

The scopes of study for this project is to examine the structure of oil palm fronds paper and other type of paper using Scanning Electron Microscope SEM and compare the image to look for similarity. The contents of the paper samples also need to determine in order to determine either oil palm fronds are suitable to make paper or not. The process is needed to be done by X-ray Fluorescence (XRF). The study about paper making process and paper testing is to identify the paper condition and physical properties of the paper. Basis weight, thickness, tensile strength and moisture content of the paper samples were determined by paper testing.

CHAPTER 2
LITERATURE REVIEW

2.1 Oil Palm Biomass

Empty fruit bunch (EFB) is a vegetable based of oil palm biomass that gets from the palm-oil extraction and milling process. With advance of technology nowadays, EFB has been used in application of industry such as a material for wood-based products (particle and fiberboards), composite panels, soil stabilization and horticultural applications. In Malaysia EFB also has been used as fuel for electricity generation. Empty fruit bunches (EFB) is a popular source of fuel for power generation renewable energy (RE). The rapid reduction of burning fossil fuels and the country's most developed countries keep track of biomass as an alternative method of power generation. Malaysia has a ready source of biomass of the empty fruit bunches (EFB) and easily collected and available for exploitation in all palm oil mills. Key results are using the RE-based power generation and biomass is a reduction in greenhouse gas emissions (GHG) [1]. In the palm oil mills, fruit bunch are sterilized through the threshing process to separate fruits nuts. The empty bunches mainly consists of a main stalk (20 – 25 %) and numerous spikelets (75 – 80 %) with sharp spines at their tips. For the years 2007 to 2020, is expected that an average of 2.856 million tonnes of empty fruit bunches (dry basis) will be issued each year [2].

Oil palm fronds (OPF) are one of the most abundant agricultural by products in Malaysia. Almost all discarded stems trimmed in farming, particularly for nutrient recycling and soil conservation [3]. Oil palm fronds has a great potential to use as a raw material to produce pulp and paper as their composition, chemical and physical properties have a similarity with other basic raw material of paper. The contents of lignin, Hemicellulose and α-Cellulose in oil palm fronds have a tally percent with other raw material of paper such as timber. Palm fronds collected during pruning and replanting activities. Availability during the crop stems is calculated using the estimated 10.4 tonnes ha-1, which now provides an average of 6.97 million tonnes per annum. Meanwhile, the average estimated at 54.43 million tonnes of oil palm fronds each year are acquired in the process of replanting in the years 2007 to 2020 [2]. Oil palm fronds are considered waste from oil palm plantations, and their biomass not fully utilized. In 1992 production from these fields by pruning and replanting programs generated about 18 million tonnes of fronds in the world. Oil palm frond was considered to be one of the new sustainable lignocellulosic raw materials if we use it effectively [4].

Oil palm trees are usually passed their economic life, on average after 25 years, and for replanting. During replanting, the length of the palm trunks cut are in the range of 7 m, 13 m, with a diameter of 45 cm to 65 cm, measured at breast height. Area due for replanting has been multiplied by the average number of 134 palms ha-1, or the amount of 1.638 m3ha-1. Approximately 53.87 % (dry weight) fiber bundles can be extracted from the stem, with the remaining parts of the parenchyma tissue of the skin and contributes to 14.45 % and 31.68 % of stem dry weight, respectively [2]. Due to replanting activities, large quantities of dry oil palm trunks will be produce every year in Malaysia starting from this decade. After felling, oil palm trunks are shredded and left to biodegrade in the fields of oil palm plantation as mulch (nutrient recycling) and also being sold to interested parties that may cost RM8-18 for each trunk. Oil palm trunks also support the industries and used to produce plywood, palm flooring (floor ply) and also furniture (laminated lumber). However, the oil palm trunks cannot be used as timber as it is and current utilization for plywood manufacture is uses only 40 %. It also highly susceptible to degradation agents and high moisture content besides have biofuel potential as contains sap that can be converted into bioethanol [5].

2.2 Characteristics of Oil Palm Biomass

Oil palm biomass contains quite significant amount of organic nutrient, which contributes to its fertilizer values [2]. Table 2.1 shows that the main oil palm biomass generated each year on palm oil plantation and at the mill. Dry matters in tone per hectare and nutrient composition (kg per hectare) for each of oil palm biomass such as oil palm trunks, oil palm fronds (replanting), oil palm fronds (pruning) and also empty fruit bunch are also shows in the table.

Table 2.1: Nutrient composition of oil palm biomass [2]

Oil Palm Biomass	Dry matters (tonne / hectare)	Nutrient (kg / hectare)			
		N	P	K	Mg
Trunks	75.5	368.2	35.5	527.4	88.3
Fronds (replanting)	14.4	150.1	13.9	193.9	24.0
Fronds(pruning)	10.4	5.4	10.0	139.4	17.2
Empty fruit bunches	1.6	107.9	0.4	35.3	2.7

In essence, the oil palm biomass contains about 20-37 % lignin, and 55-85 % holocellulose (α Cellulose and hemicellulose), which is more or less compared to wood or other lignocellulosic materials (Table 2.2). This makes the oil palm biomass is also suitable as a raw material for production of pulp and paper, composite, carbon products and chemical extraction [2].

Table 2.2: Chemical composition of oil palm biomass [6]

Component	Oil palm biomass chemical composition (wt.%)			
	EFB	Frond	Fibre	Trunk
Ash	1.3	2.4	5.6	–
Lignin	36.6	20.5	28.5	22.3
Holocellulose	82.4	83.5	59.6	–
Cellulose	62.9	49.8	–	37.14
Hemicellulose	28.0	–	20.8	–
Xylose	33.1	–	–	18.47
Glucose	66.4	–	–	31.77

Physical properties and chemical properties of oil palm biomass are significantly different because of their origins and the various types. Biomass consisted primarily of cellulose, hemicellulose, lignin and inert ash. Biomass can be converted to materials of high value commodity chemicals and fuels and now are available from fossil fuel by using the right technology. Biomass is considered as a major source of energy for humans and is expected to play a bigger role in global energy balance in the future. It contributes to about 12 % of world energy supply, while its contribution ranges is from 40 % to 50 % in many development countries [6].

2.3 Product from Oil Palm Biomass

2.3.1 Medium Density Fiberboard (MDF)

MDF is a non-structural wood-based panel of wood fibers bonded together with resin under heat and pressure. In recent years, major changes have occurred in the MDF industry. This production has increased dramatically and new plants are planned around the world. The popularity of this relatively new panel product is due to the ability to produce in the form of a molded, and in straight-edged flat panel, the host industrial markets [7]. Malaysia is one of the top five exporters of MDF in the world. The total production capacity exceeding one million cubic meters a year. Currently, most major manufacturers use rubber woods as raw material. With latex prices drop, interest in rubber only about 1.2 to 1.4 million hectares, which is approximately half the original size compared to its production a decade ago. Therefore, it is expected that the supply of rubber wood for MDF production will not be sufficient to meet the huge demand. Oil palm biomass has been tested in laboratory and pilot scale MPOB and other convenient place as a substitute for rubber wood as raw material for MDF production [2].

MDF is widely used installed at the factory and ready to assemble furniture, as well as in cabinets, underlayment, drawer front, forming, and countertops. Packaging and layers can be used to provide a typical pattern of wood grain, and a lot of wood packaging components such as door edgings, decorative trim, frames and cornices are made from MDF. In addition, MDF is replacing thin plywood and wet-process hardboard in the production of molded and flush door-skins [7]. Medium density fiberboard (MDF) is used internationally in a variety of building and construction needs. It is superior engineered wood products with great power, reliability and grooving ability for unique design. MDF offers superior quality at the finish and density and freedom from knots and natural irregularities. MDF has the characteristics of strength, durability and uniform is not always found in natural wood or particleboard. It also environmentally friendly used of wood waste to produce useful by product and the excellent machinability due to its homogenous consistency and smaller variation in needed characteristics compared to natural wood. This not occurs easily with traditional wood products [8].

2.3.2 Plywood

A study was made to produce the oil palm plywood consisting of 100% for the core, and tropical hardwood veneer face and back. Palm trunks used for making plywood were collected during replanting. Specific cutters and spin gap in the process of peeling is important for the processing of oil palm trunks, as inconsistence file vascular arrangement [2]. Currently, the potential oil profits palm veneers mainly confined to the inner layer or core in making plywood. Wood veneer used as the surface layer and back layer. Plywood products using palm oil as a veneer core has been found to provide adequate strength and useful for the use of any short-term as packaging materials. Mass consumption of oil palm trunks in the panel of the value added that can play an important role in terms of environmental pollution and sustainable use of natural resources. Use of oil palm trunks for plywood, including to the surface and back have been tested. However, more research must be conducted to improve the overall quality of the final product [9].

2.3.3 Particleboard

Particleboard manufacturing changed from oil palm biomass is expected to last a long time and research that began over 20 years ago with a few companies that try to remove particles mainly from EFB. The products are produce such as tables and chairs of schools and offices, the top of the table and cabinet. The virtues of the flat particles produced from EFB using this process is that it has high production screw strength that important to produce quality furniture [2].

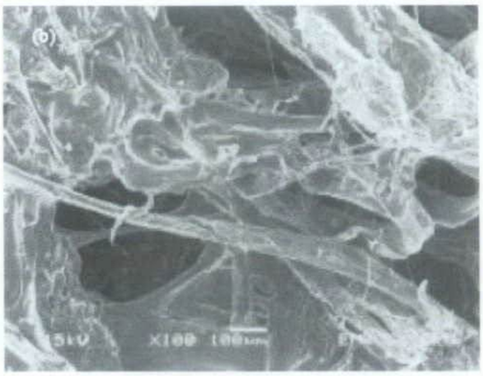


Figure 2.1: SEM image of particleboard [10]

2.4 Pulp and Paper Background

Pulp and paper industry processes large quantities of lignocellulosic biomass per years. The technology for pulp manufacture increase and many opportunities exists for the application of microbial enzymes. Historically, the enzyme found some use in the paper industry, but it has focused on such areas modification of raw starch. However, various applications of pulp and paper in industry have been identified. The use of enzymes in the pulp and paper industry has grown rapidly since the mid-1980s. Although many applications of enzymes in the pulp and paper industry are still in research and development, some applications have found their way into the mills in an unprecedented short period of time [11]. The CPPA, TAPPI, and ASTM have issued new or revised test methods for the analysis of pulp and paper matrices. Their publications should be referred to current test methodology and procedures. Significant between the new test methods is a CPPA which now recommend using acetone instead of dichloromethane to determine the amount of extractives in wood and pulp [12]. Malaysia has a relatively weak pulp and paper industry, the production does not meet domestic consumption. Half of the country's needs are imported. According to the Malaysian Pulp and Paper Association, the industry strategy is to remain domestic-market oriented [13].

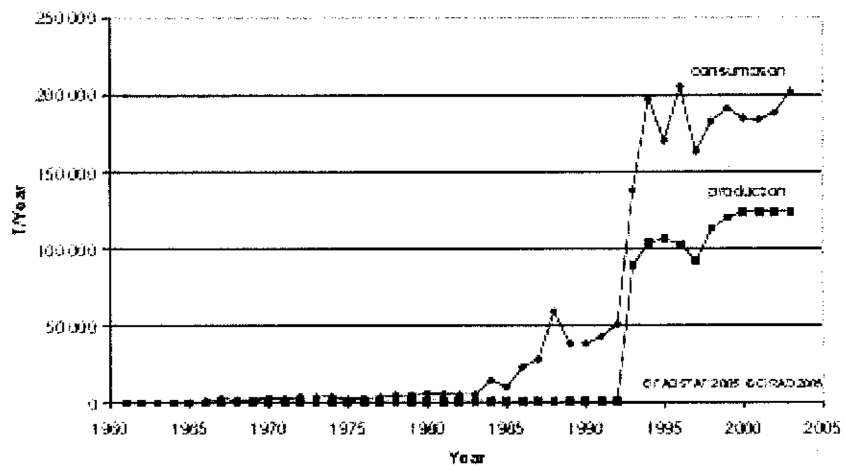


Figure 2.2: Malaysia pulp production and consumption [13]

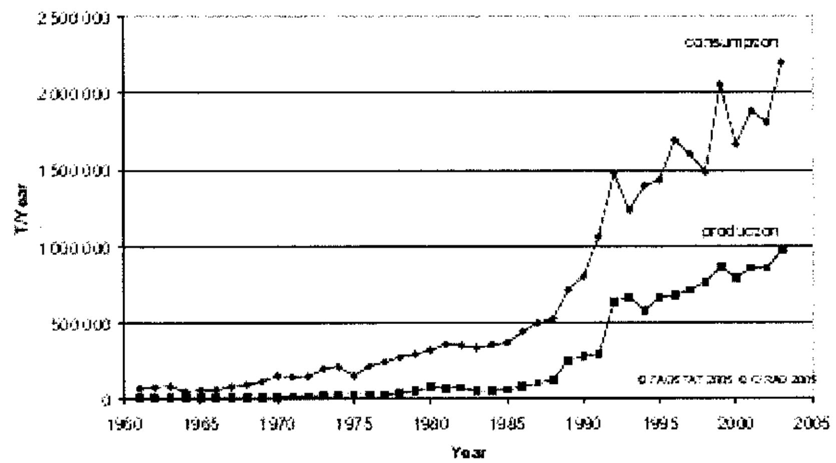


Figure 2.3: Malaysia paper production and consumption [13]

Figure shows that the production and consumption of pulp and paper in Malaysia. Based on the graph the production and consumption keep increasing year by year even though there are sometimes the performances is little bit decrease.

Malaysia is a huge importer of most paper products except toilet and tissue paper. In 1996, Malaysia's use of about 325,000 tonnes of newsprint, but produces about 5,000 tonnes. Imported paper and paper products has resulted in loss of foreign exchange, which can be reduced by using local materials lignocellulosic in the newsprint industry. One of the abundant lignocellulosic wastes is oil palm fronds (OPF).

Malaysia produced 26.2 million tonnes per year of OPF in year 2000 [14]. Wood, one of the main raw materials used in the pulp and paper industry, is made up of cellulose, carbohydrates such as starches and sugars, and lignin, which acts as an adhesive for cellulose materials. Technology in pulp and paper industry is to break the cellulose of wood to separate materials of non-cellulose. The raw material then chemically dissolved to form a pulp. Pulp slurry is then dried on a paper machine to produce a sheet of paper. Additional dyes, coatings, or preservatives may occur at the point part of the process to produce the required quality of paper or related products [15].

Pulp and paper industry is an actively water-intensive industry and can consume up to 60 m3 of fresh water per ton of paper produced. Wastewater generation and characteristics of the pulp and paper mill effluent relies on the type of manufacturing process adopted. Thus, treatment of waste water from different mills to be complicated as no two paper mills discharge effluent because of different combinations of unit processes involved in pulp and paper manufacturing [16].

2.5 Physical Properties and Paper Testing

Paper testing is important in order to measure the strength and other physical properties of various type of paper. Each paper is varying according to their type and size. Paper testing is use to determine the condition and quality of the paper and the paper then will be use in the sale and paper industries according to their performance and condition. Standard Test Method, TAPPI are testing procedures and practices relating to the use in measurement evaluation and description of pulp, paper and related products, including raw materials used in their manufacture, use, or in any scientific investigation of materials [17]. Basis weight is defined as the weight of 500 pieces of paper cut to standard sizes, usually 17 "x 22" for bond paper, 25 "x 38" text, offset, and coated paper, and 20 "x 26" for cover paper [18]. Weight per unit area, described as "basic weight" or more accurately "grammage", defines the basic properties of paper or board may be necessary to coordinate the material economic production.

The instruments to use for this purpose are divided into two main categories, a simple quadrant scale or microprocessor based digital scale. Both of the types of instruments that can accurately determine the values of grammage but the level of accuracy is achieved correctly depending on the specimen dimensions are presented [19]. It is important to note that the "basic sheet size" is not the same for all types of paper. According to TAPPI T 410, grammage of paper and paperboard (weight per unit area), the method provides the industry with a way to measure and report the mass per unit area of paper products. In general, it is reported in grams per square meter (g/m2) and commonly referred to as grammage or basis weight. It can easily be converted to a variety of rim weight. Basis weight can be used to interpret many physical properties include burst strength, tear, and tensile strength by calculating the index value.

According to Micro Format, Inc, thickness of a piece of paper is measured to produce in thousandths of an inch. The measurement is taken with a micro meter. Normally, paper caliper should not have more than 5 % variance sheet. In general, the relation between caliper and basis weight, larger caliper (thick of paper), the heavier paper. Apart from relations with the grammage, thickness can vary with furnish and treatment. It reduced the energy used during the preparation of stock due to softwood fibers collapse into the ribbon-like shape, creating a denser sheet. Improve the content of hardwood gives the contrast will increase the thickness because the thick-walled fibers and less prone to collapse [19]. According to TAPPI 411, Thickness (caliper) of paper, paperboard, and combined board, the method is to measure the thickness of a sheet of paper, paperboard, and board combination. Because of the relatively high pressures used in this test method, it may not be suitable to measure tissue or other soft materials or paper with low density, as the structure may collapse or compress.

Tensile properties are the value of materials for the identification and characterization for control and specifications purposes. Tensile properties can vary with the thickness of the specimen, method of preparation, speed test, type of grip used, and how to measure the extension. Thus, where the results are accurate comparison is required and these factors must be controlled carefully. Tensile properties can be used to provide data for research and development and engineering design and quality control and specifications. However, data from such tests cannot be regarded as important for widely different applications of the scale of the work load test. Tensile modulus of elasticity is a thin plastic stiffness index. Good reproducibility when the test results accurately maintained control over all test conditions. When different materials are compared to the stiffness, specimens of similar dimensions must be employed [20]. Based on ME 883 Physical property measurements, Lecture 3 Tensile Strength, study of deformation behavior and failure of materials, concepts stress and strain and relations between them is the key to explaining the behavior [21].

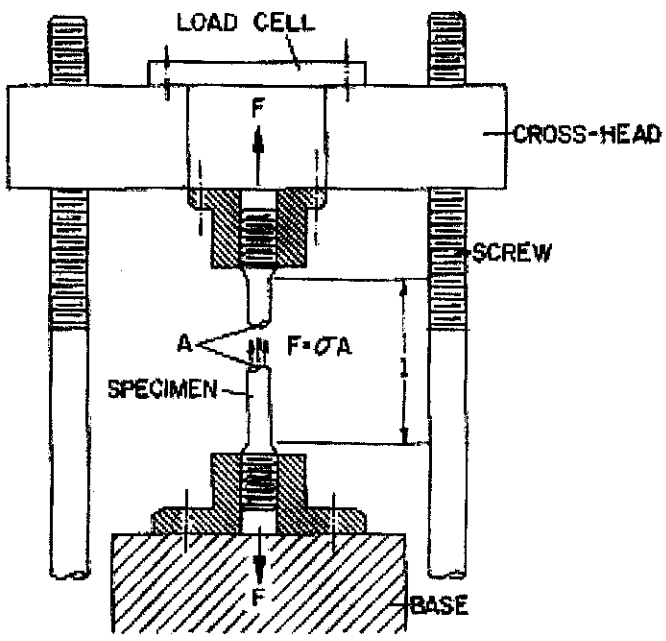


Figure 2.4: Typical Tension Test [21]

Screws that supporting the cross head is turn and increasing the force distributed over the sample cross section area A. Force divided by area is the stress,

$$\sigma = F/A$$

The displacement I of the stressed sample normalized to the dimension prior I_0 to stress is the strain

$$\varepsilon = (I - I_0)/I_0$$

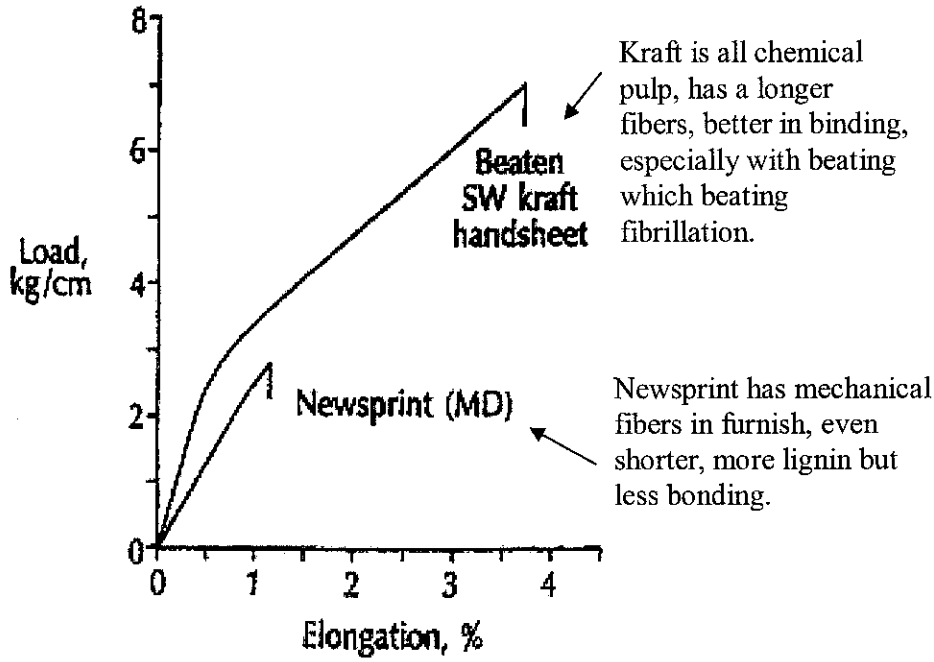


Figure 2.5: Paper Load Elongation Curves [21]

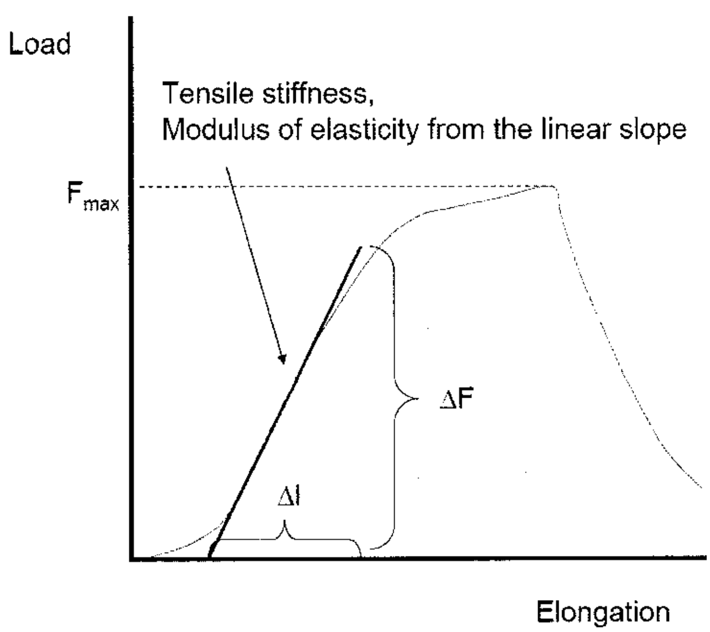


Figure 2.6: Load-elongation curve [21]

Calculations from the load displacement curves [21];

a) Tensile Index $= \frac{F_{max}}{b \times w}$

b) Elongation $= \frac{\Delta l}{l_0}$

c) Tensile Stiffness, TS $= \frac{\Delta F l_0}{b \Delta l}$

d) Modulus of elasticity, $E = \frac{TS}{t}$

w = grammage value

b = width of test piece

t = thickness of the test piece (using soft caliper or equivalent caliper)

l_0 = original length of test piece

Tensile energy to break (TEB) is the amount of energy absorbed per unit volume of the specimen until the point of breaking. In some texts this property has been referred to as toughness, used to evaluate materials that are subjected to heavy abuse or that can stall web transport equipment in the event of a machine malfunction in end-use applications. However, the rate of strain, specimen parameters, and especially flaws can cause the lack of a big change in the results. In this sense, caution is advised to use TEB test results for the design of end-use applications [20]. According to TAPPI T 494, Tensile properties of paper and paperboard (using constant rate of elongation apparatus), The tensile strength is showing strength from fiber strength, fiber length and bond. The test is done by clamping the sample line between the two clamps, one of which will remain stationary while the other exciting the sample at a fixed rate. The value of the test is reported for tensile strength, stretch, tensile energy absorption, the length of violation, and tensile index. The value of additional tests, including strength and elasticity can be calculated and reported when requested.

CHAPTER 3

METHODOLOGY

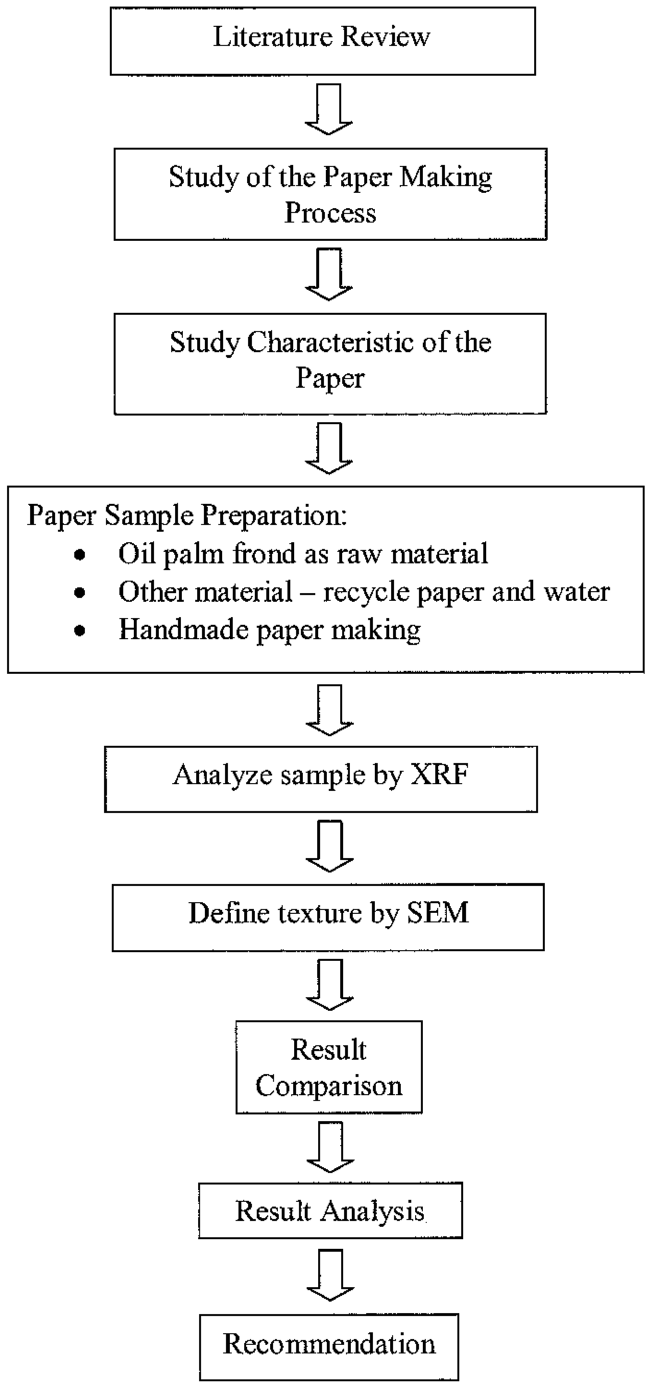


Figure 3.1: Process Flow Diagrams

3.1 Paper Making Process

The principal of raw material is cellulose fiber. As the Chinese have many years ago, when the fibers get wet, they will bond together as they dry. 95 % of the world's paper making fiber is derived from wood. Other materials, such as seeds, grasses, and plants and some synthetic materials are also use in paper making. Other important sources of cellulose fibers, is wood waste and sawdust. Seed fibers add strength, durability and texture of the paper. The most common seed fiber used in making paper is cotton seed. Currently paper recycling and paper board has become a major source of wood fiber for use in paper making [22]. This project is to study the basic paper making process that use in industries of paper making. Because of increasing demand for paper, and improvements in pulp processing technology, almost any species of tree can now be harvested for paper [23]. Usually in paper making, there are two ways to process the raw material, either through mechanical process or chemical process. In mechanical process, more than 90% mechanical pulp from wood fibers produced by forcing the debarked logs, about two meters long, and hot water in a large steel disc that rotates with teeth that literally tear apart the wood [24]. Alternatively, the timber can be pressed against the grindstones and turning the logs into pulp by pressing it between huge revolving slabs. The pulp is filtered to remove foreign objects.

The trees contain 30 % of lignin, a substance that sensitive to light and degrade, and also turn brown when expose to the sun, which explains why the paper made from mechanical pulp will discolor. As an example is newsprint. Newsprint is designed to have a short lifetime, and if left for long periods it will be lost whiteness and strength. Special advantage of mechanical pulp is that it makes the paper opaque and large [24]. In chemical process, chips from storage bins were put into the digester while chemicals have been added. Woodchips is 'cooked' to remove lignin which is the binding material that holds cellulose fibers together. Chips were 'cooked' by the heat and pressure in a caustic soda and sulfuric. The chips dissolve into pulp in the solution. The chemical process of self-sufficient for almost all products can be used to fire the mill power plants. The mechanical process in paper making was produce better fibre yield compared to chemical process, typically 50-60% [24].

Beating or refining processes are very important in the paper making process. An examination of beating, in particular, provides several insights as to some of the technology involved. Bleaching is optional in paper making and use to increase the whiteness of the paper. The sheet that has whiter in color has better contrast with ink. Old-style pulp mills use chlorine compounds with hazardous side-effects. Modern pulp mills use oxygen-based bleaching (compounds like oxygen, ozone and peroxide). For some applications, the bleaching process is not required, for instance for packaging paper and board. Refining is a separate process step in which the fibre surfaces are "roughened". The greater surface roughness of a fibre, the better it adheres to other fibres in the paper sheet and even the strength in higher [25]. This is where the cellulose fiber passes through the important process of refining, art of papermaking. Prior to filtration, fiber bonds some stiff, not flexible and shape. Stock pumped through the machine consisting of a series of round discs. Violent abrasive and bruising action affect the cutting, opening up, and declustering fibers and make the end of the gap. This is called fibrillation. In this case, the fibers are pliable and have a larger surface area, which significantly increases the fiber bonding. Paper properties are directly related to the refining process. Refining process used to call a beating process [24].

Pulps usually contain unneeded fibrous and non-fibrous materials, which have to be removed prior the pulp is made into paper or board in screening process. Cleaning process involves the process that removing small particles of dirt and grit using rotating screens and centrifugal cleaners [24]. To finally turn pulp into paper, pulp fed or pumped into the machine. Pulp included in the Fourdrinier machine on a moving belt of fine mesh screening. The pulp is squeezed through a series of rollers, while the suction devices below the belt of water flowing. If the paper is to receive a water-mark, a device called a dandy moves across the sheet of pulp and presses a design into it. The paper then moves to the press machine, where it is pressed between rollers wool felt. Then it passes through a series of papers steam-heated cylinders to remove any water remaining. A large machine may have 40-70 of drying cylinder [23].

Finally, dry paper wound into a large drum, where it will continue to be processed depending on final use. Paper smoothed and compacted again with the metal rollers called calendars. Certain finishes, whether soft or hard and shiny bore, can be produced by the calendar. Paper can be directly done by passing through a vat of sizing material. It can also receive a coating, which is either brushed or rolled on. Coating is adding chemicals or pigments on the surface of the paper, supplementing the sizing and filler from the beginning of the process. Fine clay is often used as a coating. The paper then runs in calendar rollers, for the last time the sheet is cut to required size [23].

3.2 Characteristic of the Paper

Chemical composition of paper is the determining factor of pulping yield for various pulping processes. Paper is mainly composed of cellulose, Hemicelluloses, lignin. Table 3.1 and table 3.2 shows that the percent of these components that contains in the pulp and vary based on pulping process. The physical properties of the paper are also based on pulping process. Paper making properties such as initial tensile, maximum tensile and tear is measured by their performance either low, medium, medium high, high or very high. The components in the pulp can be removed by various pulping process.

Table 3.1: Chemical composition of paper [26]

Pulping Process	**Yield (%)**	**% of Pulp**			**Papermaking Properties**		
		α Cellulose	**Hemicellulose**	**Lignin**	**Initial Tensile**	**Max. Tensile**	**Tear**
Kraft	44	None	14	1-2	Low	Very High	Low
Sulfite	50	High	11	1-2	Medium	Medium	Medium
Alkaline Pretreatment With Sulfite Cook	52	Medium	17	1-2	Medium High	Medium	Very High
High Yield Bi-Sulfite	60	Low	19	10	High	High	Low

Table 3.2: Chemical composition of paper [26]

Pulping Process/Pulp Grade	**Wood Components Retained in Pulp**	**Wood Components Removed**	**Yield**
Soft Chemical Cook and Bleached	Cellulose only	Lignin, Hemicelluloses & Extractives	Less than 40%
Chemical Pulping & Bleached	Cellulose and partly Hemicelluloses	Lignin, partly Hemicelluloses & Extractives	45 - 55%
Chemical Pulping NO Bleaching	Cellulose, partly Hemicelluloses & traces of Lignin	Partly Lignin & Hemicelluloses & Extractives	45 - 55%
Semi-Chemical	Cellulose, mostly Hemicelluloses & partly lignin	Partly lignin, some Hemicelluloses &Extractives	50 - 65%

3.2.1 Cellulose

It is a high molecular weight, stereoregular, and linear polymer of repeating beta-D-glucopyranose units. In other words it is the chief structural element and major constituents of the cell wall of trees and plants [26]. For industrial use, cellulose is mainly obtained from wood pulp and cotton. It is mainly used to produce paperboard and paper; up to a lesser extent, it was converted to a variety of derivative products such as cellophane and rayon. Converting cellulose from energy crops to biofuels such as cellulosic ethanol is under investigation as an alternative fuel source [27]. Dissolving pulp used in the production to produce cellulose. Cellulose is dissolved in organic solvents and processed to regenerate the cellulose in different forms. Sulfite content of 90-92 % cellulose pulps are mainly used to make textiles (such as rayon) and cellophane. 96 % cellulose content sulfate of pulps used to make rayon yarn for industrial products such as tire cord, rayon staple for high-quality fabrics, and acetate range and other specialized products [28].

3.2.2 Hemicelluloses

A constituent of woods that is, like cellulose, a polysaccharide, but less complex and easily hydrolysable. Hemicelluloses have lower degree of polymerization (only 50 - 300) with side groups on the chain molecule and are essentially amorphous [26]. Hemicellulose is any of several heteropolymers (matrix polysaccharides), such as arabinoxylans, was present along with cellulose in almost all plant cell walls. Although the cellulose crystals, strong, and resistant to hydrolysis, hemicellulose has a random, amorphous structure with little strength. It is easily hydrolyzed by diluted acids or bases as well as a variety of hemicellulase enzymes [30].

3.2.3 Lignin

A complex chemical compound most commonly derived from wood, and an integral part of the secondary cell walls of plants. Lignin is brown in color. Lignin is largely responsible for the strength and rigidity of plants [26]. Lignin is a chemical compound or complex lignin, most commonly derived from wood, and is part of the secondary cell walls of plants [30] and some algae [31]. The term was introduced in 1819 by de Candolle and comes from Lignum [32] in Latin, meaning wood. It is one of the most abundant organic polymers on earth, exceeded only by cellulose, which takes 30% of non-fossil organic carbon [33] and form from the third quarter of the dry mass of wood. As a biopolymer, lignin is unusual as its heterogeneity and lack of a defined primary structure. Its most commonly noted function is the support through strengthening of wood (xylem cells) in trees [34][35][36].

3.3 Properties of Paper

3.3.1 Basis Weight and Grammage

Weight is the most common specification because most paper is sold on a weight basis. Weight of paper is expressed per unit of area rather than per unit of volume. The common unit for expressing the weight of paper is the number of pounds of paper per ream. The mass per area of the paper is measured as gsm (grams per square meter). The procedure of measuring grammage value is done by Monitor Basis Weight Scales according to standard in TAPPI T 410, SCAN P6, DIN53104 & ISO: BSENISO536. Grammage value was calculated by formula;

$$\frac{\text{Basis Weight x 1406.5}}{\text{Basic Size}} = \text{Grams per square meter}$$

3.3.2 Thickness

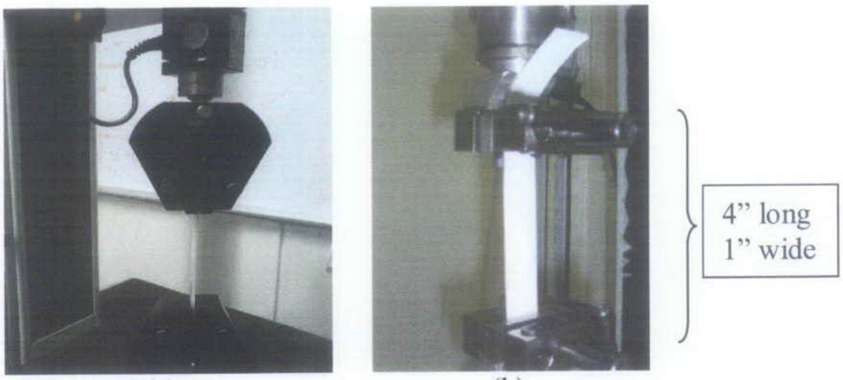
Thickness is measured by Digital Micrometer: 49-60 as the distance between two circular plane surfaces of a standard size under a standard pressure. The result shows in μm. The thickness of the paper affects nearly every physical and optical property, and uniform thickness across the sheet is important for printing. The procedure for thickness measurement is done according to standard in TAPPI T 411.

3.3.3 Tensile Strength

Tensile strength is indicative of fiber strength, fiber bonding and fiber length. Tensile strength can be used as a potential indicator of resistance to web breaking during printing or converting. Faster rate of elongation results in higher tensile strength, log relationship with rate. 1 inch wide strips and 4 inches long of paper have use for testing. At the low levels of bonding, tensile strength is dependent on interfiber bond strength and fiber length. At high levels of bonding there is greater dependence on fiber strength. Paper with highest level of strength with minimum amount of fiber is a high quality paper. The procedure for tensile index measurement is done according to TAPPI T 494 [37].

Tensile index = tensile strength (N/m) / grammage (g/m^2).

Stretch (sometimes evaluated in conjuction together with the bending resistance) is the ability of paper to comply with the desired contour, or non-uniform tensile stress. It should be considered important in all the papers, but a certain interest in the paper where the nature of the stress-strain properties are being modified or controlled. Stretch was assessed in a particular grade of paper decorations and industries such as paper and packaging tape, both as an index of a paper in accordance with the irregular shape and with the tensile energy absorption, as a performance indicator paper under both conditions either dynamic or repetitive strain and stress. Stretch also important in reducing the frequency of breaks on high speed web fed printing presses such as used to print newspaper. The strength of the paper specimens will be determined by using the 5KN Universal Testing Machine. The test will be carried out according to standard in TAPPI T 494 and TAPPI T 220 “Physical Testing of Pulp Handsheets.”



(a) (b)

Figure 3.1: Universal Testing Machine

Figure 3.2: Cutter for 1”wide samples

3.3.4 Moisture Content

The procedures of moisture content are done according to standard in TAPPI T 412 and ISO 287, SCAN P4. Almost all grades of paper have some moisture percentage. Moisture in the paper differs from 2-12% depending on the humidity, the type of pulp used, the level of refining and chemicals used. Most of the physical characteristics of paper as a result of changes in moisture content variation. Water has a plasticizing effect of cellulose fiber and relaxing and weakening the bond between the fibers. Electrical resistance and dielectric constant both papers different with moisture content. Absorption and reflection of a particular band infrared and microwave radiation by the paper is affected by moisture content. The amount of water present in the sheet of paper is usually expressed as a percentage. The amount of water plays an important role in the calendar, print and changes the process. Moisture control is also important to the economic aspects of paper making. The water comes free. Poor moisture control can affect many properties of paper [26].

$$\text{Moisture content} = \frac{\text{initial specimen weight} - \text{dry specimen weight}}{\text{Initial specimen weight}}$$

3.4 Sample Preparation

3.4.1 Process Flow Diagram

Figure 3.3: Oil palm tree

⇩

Figure 3.4: Oil palm fronds

⇩

Figure 3.5: Oil palm fronds powder

⇩

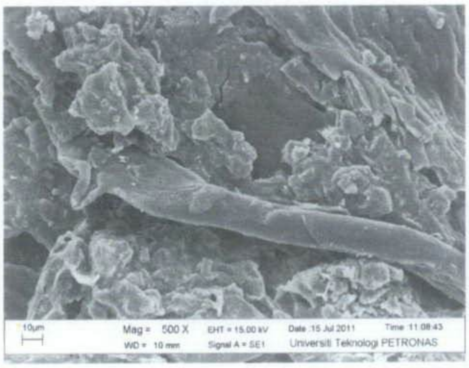


Figure 3.6: SEM image of oil palm frond

⇩

Figure 3.7: Product of raw material oil palm fronds pulp

⇩

(Handmade Paper Making)

Figure 3.8: Handmade Paper Making Process

Plastic container lid was lined with a piece of plastic or parchment paper. This makes turning the paper out easier. Then paper pulp was press into the mold. The paper pulp was press firmly into the mold trying to get an even distribution.

⇩

Figure 3.9: Handmade Paper Making Process

Towel used to press firmly on the paper pulp to remove the water. The lid was tip slightly so any water can run away. The towel was press harder to ensure more water will be removed and the firmer the end result.

⇩

Figure 3.10: Handmade Paper Making Process

When the paper is firm and as much water as possible has been removed, the paper was turned out onto a dry towel which has been placed on a flat surface. Dry towel used to press more water from the paper. The paper was placed in a warm and dry spot to dry.

⇩

Figure 3.11: Product of oil palm fronds (paper)

3.5 Analyze sample by X-ray Fluorescence (XRF)

Table 3.3: Chemical Compositions of Oil Palm Fronds (OPF) [38]

Component	Oil palm fronds
Lignin (%)	15.2
Hemicellulose (%)	33.9
α-Cellulose (%)	49.8
Alcohol–benzene extractives (%)	1.4

The properties of the oil palm fronds used in this study were analyzed. The results of the X-ray Fluorescence (XRF) analysis are summarized in table 3.3. It is noted that Lignin, Holocellulose, α-Cellulose were the primary components found in the OPF. Some little percent of Alcohol–benzene extractives still got in OPF contents.

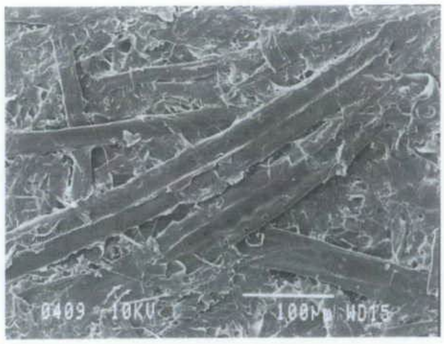
Table 3.4: Physical properties of OPF [39]

Properties	Oil palm frond
Grammage g/m^2	103.2
Thickness (μm)	200
Tensile Index (Nm/g)	51.59
Moisture content %	7.39

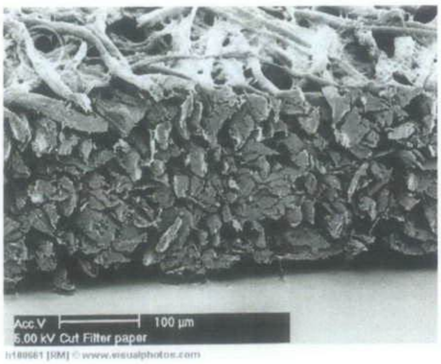
Data from table 3.4 has been collected by research and sample testing of grammage value was done according to TAPPI T 410 "Grammage of paper and paperboard (weight per unit area)". Thickness value was determined by TAPPI T 411 "Thickness (caliper) of paper, paperboard, and combined board". Tensile index was done according to standard in TAPPI T 494 and TAPPI T 220 Physical Testing of Pulp Handsheets. Moisture content of OPF was measured by TAPPI T 412. Both tensile index and moisture content relatively depend on the value of grammage. In other words the grammage value is important in determining physical properties of paper.

3.6 Analyze sample by Scanning Electron Microscope (SEM)

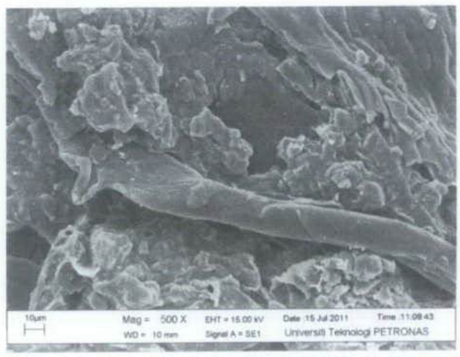
(a)



(b)



(c)



(d)

Figure 3.12: SEM image of the samples

(a) SEM image of bond paper [40]

(b) SEM image of newspaper [41]

(c) SEM image of filter paper [42]

(d) SEM image of oil palm fronds

CHAPTER 4

RESULT AND DISCUSSION

4.1 Paper Analysis

4.1.1 Bond Paper

Bond paper is a writing paper with high durable quality similar to bank paper but having a greater weight of 50 g/m2. Bond paper standard weight is 20 pounds, mean 500-sheet ream-sized bond paper in 17 by 22 inches weight 20 pounds. But before the paper is sold to consumers, it should be cut to a standard letter size of 8.5 by 11 inches. When the paper is cut, each 500-sheet ream of paper weight is 5 pounds. It is used for letterheads and other stationery and as paper for electronic printers. Widely used for graphic work involving pencil, pen and felt tip markers. It is mainly made from rag pulp which produces a stronger paper from wood pulp [43]. Nowadays, bond paper currently known as being a smooth white sheet commonly made from normal eucalyptus pulp.

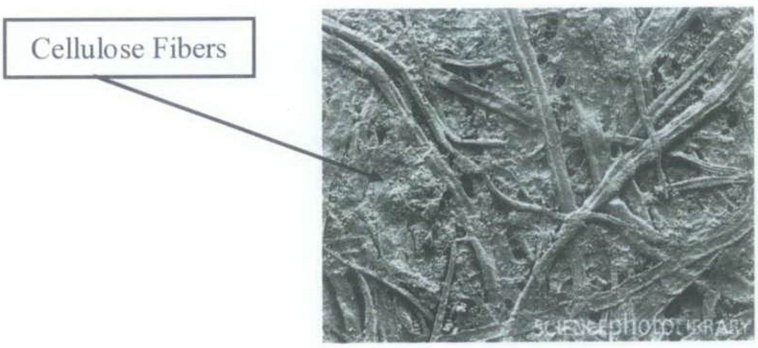


Figure 4.1: Bond paper by SEM. The components of cellulose fibers are visible [40]

Table 4.1: Physical properties of bond paper

Properties	Bond Paper
Grammage g/m^2	80
Thickness (μm)	115
Tensile Index (Nm/g)	70
Moisture content (%)	4

4.1.2 Newspapers

Newspapers printed on paper that a combination of recycled materials and wood pulp. They used to be printed on textile materials such as cotton or linen. Before pressing the block of modern times has been used, they have a place to set the letters and then put ink on the letter and then pressed onto the paper. All day is done on larger machines that are more like assembly-line production of large-scale and paper rolls are rotated at major [44]. A newspaper is made up of a bunch of short stories and articles that tell the news. It is created through a printing press that can produce many notes at a time. About 80% of newspaper ink is made from plant-based ink, but others, especially those made from petroleum-based inks. Since 2004, 95% of American newspaper ink is now soy based, as opposed to petroleum based. It is not considered to be 100% biodegradable, however, because it is still mixed with additives, resins, pigments, and waxes [45].

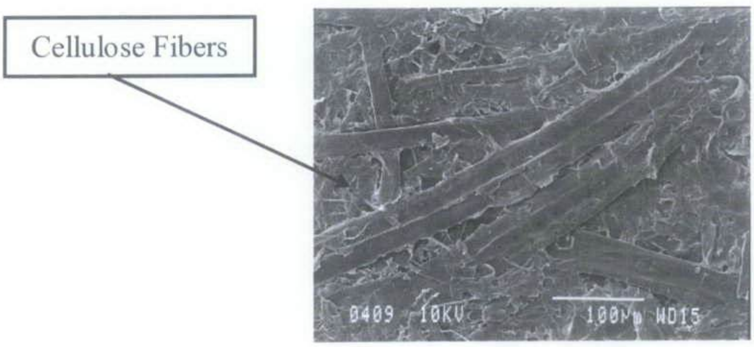


Figure 4.2: Scanning electron micrograph (SEM) of paper used to make newspapers. The paper consists of cellulose fibres glued together [41].

Table 4.2: Physical properties of newspaper

Properties	**Newspaper**
Grammage g/m2	45
Thickness (μm)	100
Tensile Index (Nm/g)	40
Moisture content (%)	8.5

4.1.3 Filter Paper

Filter paper made of raw materials of different paper pulps. Be of softwood pulp, hardwood, fiber crops and mineral fibers. For filter paper with high quality, dissolving pulp and mercerized pulp are used. Filter paper usually carried out on a small paper machines. For laboratory filter the machine may be as small as 50 cm width. Filter paper grade and variety of porosities are depending on the application intended for. Important parameter is the wet strength, porosity, particle retention, flow rate, compatibility, efficiency and capacity. There are two filtering mechanisms for the paper which is volume and surface. By volume filtration the particles are caught in the bulk of the filter paper. By refining the surface of the particles captured on the surface of the paper. There are many type of filter paper such as air filter, coffee filter, fuel filter, laboratory filter, oil filter, and tea bag filter [46].

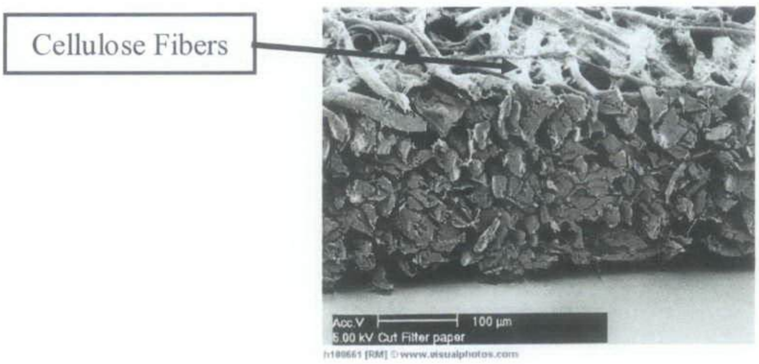


Figure 4.3: Filter paper: Scanning electron micrograph (SEM) of the cut end of a piece of filter paper showing its many cellulose fibres.

Table 4.3 Physical properties of filter paper

Properties	**Filter Paper**
Grammage g/m2	50
Thickness (µm)	180
Tensile Index (Nm/g)	50.5
Moisture content (%)	9

4.2 Lignin, α Cellulose and Hemicellulose content

Table 4.4: Chemical Compositions of the samples [26]

Component	Bond Paper	Newspaper	Filter Paper	Oil Palm Fronds
Lignin (%)	10.5	33	23.4	15.2
Hemicellulose (%)	19.2	30.6	28.5	33.9
α-Cellulose (%)	45	39.5	40.0	49.8

4.2.1 Lignin

Lignin is largely responsible for strength and rigidity of plants. Lignin that exposure to air and sunlight may turn paper yellow. Papers will be darkened as more lignin in it. To make a smooth white paper, the mill puts the wood through a chemical solvent process, which separates and discards the lignin. Pure cellulose is basically white, and paper made from it will be white and resist yellowing. Lignin eventually turns yellow on paper because of oxidation. That is, the lignin molecules, when exposed to oxygen in the air, began to change and become less stable. Lignin will absorb more light, giving off a darker color [47].

Some pulping processes are implemented to remove as much lignin as possible, while others are designed merely to separate the fibers so as to allow banding. The more lignin is removed, up to a certain point, the more bonding can take place, and the stronger the paper [48]. A naturally occurring component of plant life that helps provide strength in plants, lignin is often removed from paper during paper manufacturing to improve the quality and life of the paper [49]. Based on table 4.4, we can see that OPF has 20.5% of lignin content. This means that from OPF we still can make paper even in average quality. The product also will have darker in color.

4.2.2 Hemicellulose and α-Cellulose

Based on table 4.1 we can see that Hemicellulose and α-Cellulose content in OPF is higher compared to the other samples. Hemicellulose and α-Cellulose is the most common organic compound on Earth. About 33% of all plant matter is based on these components. When cellulose are soaked in water (do not work on other liquids such as alcohol) hydrogen bonding occurs among the hydroxyl (-OH) groups on the surface of the fibers that may cause them to cling together. After these bonds are established, drying process causes these bonds to strengthen even more, resulting in a strong sheet or mesh of fibers that we call paper [50]. Hemicellulose and α-Cellulose are important to determine the quality and durability of paper. With the high content of the components, OPF is suitable to make pulp and paper [26].

Table 4.5: Physical properties of the samples

Properties	Bond Paper	Newspaper	Filter Paper	Oil Palm Fronds
Grammage g/m^2	80.0	45.0	50.0	103.2
Thickness (μm)	115	100	180	200
Tensile Index (Nm/g)	70.0	40.00	50.50	51.59
Moisture content %	4.00	8.50	9.00	7.39

Some of the testing has been done to various type of paper. Table 4.5 indicates that the comparison of the physical properties of the paper samples. It shows that the grammage value of the oil palm frond paper is 103.2 g/m^2 as the weight of a sheet of OPF paper is 0.014 lbs. The thickness of OPF paper is 200 μm as measured by screw micrometer. The tensile index of OPF is 51.59 Nm/g, average value from all the samples. Moisture content for OPF paper is 7.39 %.

Table 4.6 Tensile Index Data

Type of Paper	Sample	Tensile Strength (N/m)
Bond Paper	1	0.879
	2	0.873
	3	0.870
	4	0.875
	5	0.878
	Mean	0.875
	Grammage (g/m2)	80.000
	Tensile Index (Nm/g) = Tensile Strength x Grammage	70.000
Newspaper	1	0.882
	2	0.885
	3	0.892
	4	0.890
	5	0.895
	Mean	0.888
	Grammage (g/m2)	45.000
	Tensile Index (Nm/g) = Tensile Strength x Grammage	40.000
Filter Paper	1	1.020
	2	0.993
	3	0.994
	4	0.991
	5	1.050
	Mean	1.010
	Grammage (g/m2)	50.000
	Tensile Index (Nm/g) = Tensile Strength x Grammage	50.500
Oil Palm Fronds Paper	1	0.497
	2	0.489
	3	0.493
	4	0.516
	5	0.506
	Mean	0.500
	Grammage (g/m2)	103.200
	Tensile Index (Nm/g) = Tensile Strength x Grammage	51.590

Based on table 4.6, the data of tensile strength of bond paper, newspaper, filter paper and oil palm fronds paper have been collected by using the 5KN Universal Testing Machine. The test has been carried out according to standard in TAPPI T 494 and TAPPI T 220 "Physical Testing of Pulp Handsheets." Based on the data of tensile strength for 5 samples, the average of each tensile strength has been determined, then the tensile index was calculated by the formula;

Tensile Index = Tensile Strength x Grammage

Tensile index is measured in Nm/g. According to the data, tensile index shows the strength of each of the samples. High quality of paper was measured according to higher tensile index. Table 4.6 shows that bond paper has the higher quality as the value of tensile index is higher. Oil palm fronds paper has the value 51.90 Nm/g, that is means the quality of oil palm fronds paper still in average and proved that oil palm fronds are acceptable to make paper in pulp and paper production.

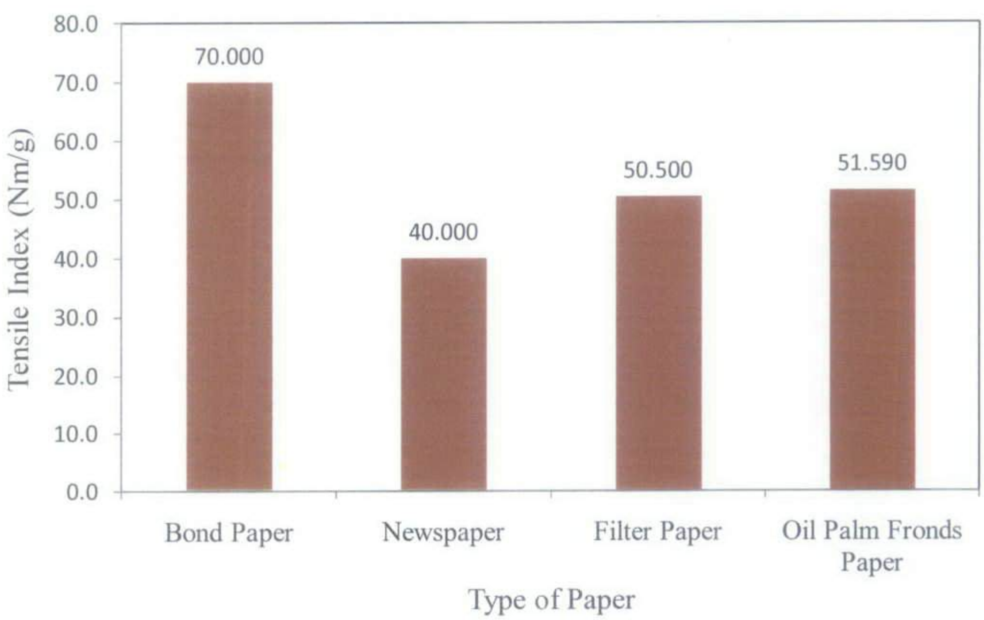


Figure 4.4 Tensile Index VS Type of Paper

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

The oil palm fronds paper has grammage value of 103.2 g/m^2, thickness of 200 μm, tensile index of 51.59 Nm/g and 7.39 % of moisture content. They have lignin, hemicellulose and α-cellulose content of 15.2 %, 33.9 % and 49.8 % respectively. This project gives an overview on the potential of oil palm biomass as the raw material in pulp and paper production. From the research that had been done so far, as the conclusion, the results obtained in the analyses and experiments, show that OPF is an excellent raw material for the production of pulp and paper. Moreover, the chemical and physical properties of OPF make it suitable for paper making. The paper that can be produced from OPF will have a good characteristics and high quality, such as tensile index. However, it must be pointed out that the OPF pulp used in this study was not properly cleaned because at the time the necessary equipment was not available, so better results can be expected with this pulp by introducing cleaning steps in the process.

It is possible to produce paper made from oil palm frond, because of its chemical and physical properties. However, other properties require further studies. With further research and development, overall performance of the OPF could be improved for pulp and paper production in the near future and also led to better demand and prices for palm oil in oil palm industry. The successful use of agriculture wastes such as oil palm frond is positive steps undertaken to reduce the dependence on tree and decrease the abundant of oil palm waste in our country. The findings show that Malaysia has the potential to be one of the major contributors of renewable source of paper in the world via oil palm biomass. Subsequently, Malaysia can then become a role model to other countries in the world that has huge biomass feedstock.

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APPENDIX

Appendix A: Milestone

No	Details/Week	1	2	3	4	5	6		7	8	9	10	11	12	13	14
1	Selection of Project Topic	■	■					Mid-semester break								
2	Research about paper making process		■	■	■	■	■									
3	Submission of Preliminary Report				●											
4	Project work and study about characteristic of paper					■	■									
5	Submission of Progress Report									●						
6	Seminar									●						
7	Work continues								■	■	■	■	■	■	■	
8	Submission of Interim Final Report Final Draft															●
9	Oral Presentation									During Study Week						

● Milestone

■ Work activities

Figure A-1: Gantt chart and Project work for FYP 1

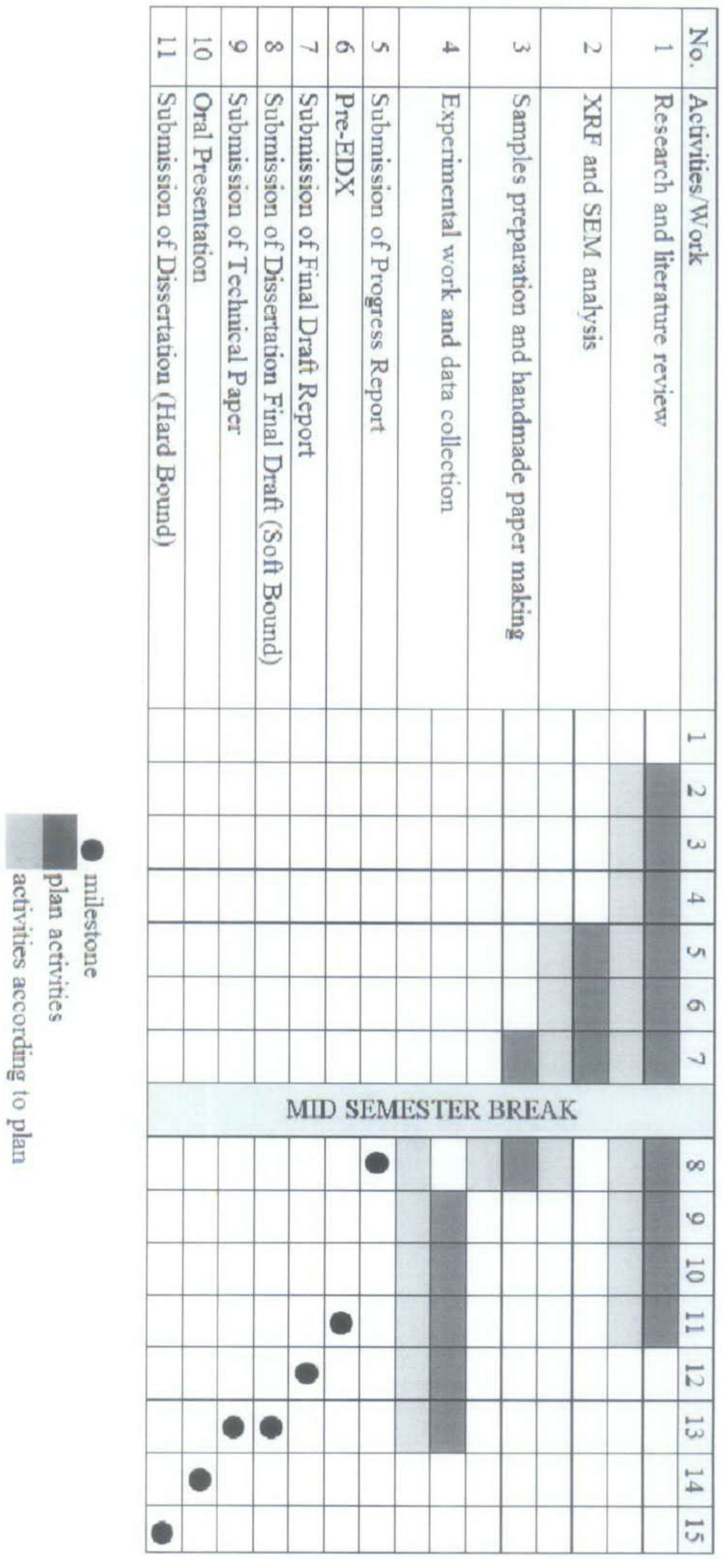

Figure A-2: Gantt chart and Project work for FYP 2