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**Effects of Filler Components on Mechanical  
Properties and Machinability Characteristic of  
Palm Oil Based Wax**

by

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A thesis submitted

In fulfilment of the requirements for the degree of  
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**Pengaruh Komponen Pengisi Pada Sifat Mekanikal Dan Ciri-Ciri Kesan  
Pemesinan Pada Lilin Kelapa Sawit**

**ABSTRAK**

Tesis ini membincangkan penyelidikan lengkap pada campuran lilin kelapa sawit dengan LLDPE dan HDPE. Sasaran penyelidikan ialah untuk menghasilkan campuran lilin industri murah yang di buat daripada lilin kelapa sawit. Campuran lilin yang di kaji adalah terdiri daripada lilin industri komersial untuk tujuan permodelan fizikal CNC. Kajian struktur bahan seperti sturuktur mikro telah di jalankan sebelum menambah pengisi dan selepas penambahan pengisi. Keputusan kajian telah menunjukkan bahawa pelbagai jenis pengisi akan mempengaruhi sifat-sifat mekanik dan akhirnya akan menyumbang kepada kekuatan struktur bahan campuran tersebut. Keberkesanan campuran pengisi dengan lilin kelapa sawit di nilai dengan menggunakan teknik yang berbeza seperti kajian terma, mekanikal dan juga SEM melalui kajian struktur bahan. Keberkesanan campuran terbaik telah didapati daripada campuran 30%wt LLDPE + 20%wt lilin kelapa sawit + 0%wt fiber kelapa sawit untuk pengisi LLDPE dan 70%wt HDPE + 20%wt lilin kelapa sawit + 0%wt fiber kelapa sawit untuk pengisi HDPE di mana pada peringkat ini kekuatan tarikan dikatakan mempunyai nilai tertinggi. Pengisi LLDPE dianugerahkan kelicinan permukaan terbaik selepas melalui ujian kelicinan permukaan setelah mendapat nilai Ra terendah iaitu 1.966  $\mu\text{m}$ .

**Effects of Filler Components on Mechanical Properties and Machinability  
Characteristic of Palm Oil Based Wax**

**ABSTRACT**

*This thesis presents, a comprehensive study on the blends of palm oil based wax with filler components such as linear low polyethylene (LLDPE) and high density polyethylene (HDPE). The work targets the development of cheap industrial wax made from palm oil. The blends studied comprised of commercial industrial wax for prototyping Computer Numerical Control (CNC) machining purpose. Morphological analysis also has been carried out to investigate microstructure before composing filler and after filler compositions. The experiment results show that different kind of filler will affect mechanical properties and will attribute to strength of blends materials. The effectiveness of compatibility filler was evaluated using different techniques like thermal, mechanical and scanning electron microscopy via morphology study. Best compatibilization effect was found in the blend at loading of 30%wt LLDPE + 20%wt raw palm oil based wax + 0%wt palm oil fiber for LLDPE filler and 70%wt HDPE + 20%wt raw palm oil based wax + 0%wt palm oil fiber for HDPE filler where at these compositions, the tensile strength is at the highest level. LLDPE filler blends was awarded best smooth surface after obtain 1.966 $\mu$ m (Ra) value.*

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## LIST OF ABBREVIATIONS

CNC	Computerized Numerical Control
DOE	Design of Experiment
RM	Ringgit Malaysia
ASTM	American Society for Testing and Materials
DSC	Differential Scanning Calorimetry
FTIR	Fourier Transform Infrared
HDPE	High Density Polyethylene
LDPE	Low Density Polyethylene
LLDPE	Linear Low Density Polyethylene
PE	Polyethylene
SEM	Scanning Electron Microscopy
ANOVA	Analysis of variance
SS	Sum of square
MPOB	Malaysia Palm Oil Board



## CHAPTER 1

### INTRODUCTION

#### 1.1 Palm oil based wax

##### 1.1.1 Introduction to fatty acid

Fatty Acids are aliphatic carboxylic acid with varying hydrocarbon lengths at one end of the chain joined to terminal carboxyl (-COOH) group at the other end. The general formula is  $R-(CH_2)_n-COOH$ . Fatty acids are predominantly unbranched and those with even numbers of carbon atoms between 12 and 22 carbons long react with glycerol to form lipids (fat-soluble components of living cells) in plants, animals, and microorganisms.

Fatty acids all have common names respectively lauric (C12), Myristic (C14), palmitic (C16), stearic (C18), oleic (C18, unsaturated), and linoleic (C18, polyunsaturated) acids. The saturated fatty acids have no double bonds, while oleic acid is an unsaturated fatty acid has one double bond (also described as olefinic) and polyunsaturated fatty acids like linolenic acid contain two or more double bonds. Lauric acid (also called Dodecanoic acid) is the main acid in coconut oil (45 - 50 percent) and palm kernel oil (45 - 55 percent). Nutmeg butter is rich in myristic acid (also called Tetradecanoic acid ) which constitutes 60-75 percent of the fatty-acid content. Palmitic acid (also called Hexadecylic acid ) constitutes between 20 and 30 percent of most animal fats and is also an of most important constituent vegetable fats (35 – 45% of palm oil). Stearic acid ( also called Octadecanoic Acid) is nature's most common

long-chain fatty acids, derived from animal and vegetable fats. It is widely used as a lubricant and as an additive in industrial preparations. It is used in the manufacture of metallic stearates, pharmaceuticals, soaps, cosmetics, and food packaging. It is also used as a softener, accelerator activator and dispersing agent in rubbers. Oleic acid (systematic chemical name is cis-octadec-9-enoic acid) is the most abundant of the unsaturated fatty acids in nature.

## 1.2 Introduction to Polyethylene (PE)

Polyethylene (PE) was discovered in 1933 by Reginald Gibson and Eric Fewcett at the British industrial giant, Imperial Chemical Industries (ICI). PE is the highest volume polymer in the world. It is a polymer made up a repeat unit of ethylene,  $\text{CH}_2 = \text{CH}_2$  where the chemical formula is  $(-\text{CH}_2 - \text{CH}_2-)_n$ . PE was produced at high pressure and temperature in the presence of catalyst. The first generation of PE contains both long and short bunches with versatile material that offered high performance compared to other polymers.

With advances in catalyst technology and reactor design, different PE molecular structures can be produced with different physical properties. These new development exhibits has indeed increase the product versatility. (Colvin,R.,2002).

The outstanding of PE are toughness, ease of processing, chemical resistance, abrasion resistance, electrical properties and impact resistance. PE offers combination of characteristics that are suited for many applications. PE properties can be tailored by changing the polymerization method or reaction conditions. For example the food

packaging application, these products are better synthesized in solution polymerized linear low density polyethylene. The polymer chain length, degree of crystallinity and the mechanical properties of polymers can be controlled by adding specific amount of co monomers to the reactor.

### **1.3 Types of Polyethylene**

High density polyethylene (HDPE) is a flexible and translucent material. Its main qualities are toughness, rigidity, good abrasion resistance, high stress breaking resistance and good chemical resistance. It is easy to process by most method with low cost. HDPE is more rigid and harder than low density polyethylene. HDPE has exceptional impact strength and is one of the best impact-resistant thermoplastic available. Its properties can be maintained in extremely low temperatures. It can be used in fresh water and salt water immersion applications. (Vasile, Cornelia 2005).

Low density polyethylene (LDPE) is a semi-rigid and translucent material. Its main qualities are toughness, flexibility, resistance to chemicals, low water absorption and excellence electrical properties. It is easy to process by most methods with low cost. It cannot be used in extremely high temperature. However it is an excellence material for corrosion resistance. LDPE has lower melting point and higher clarity if compared to HDPE due to long side chain branching. LDPE has a very good flow behavior, flexible and tough at low temperature and transparent. (Vasile, Cornelia 2005).

The disadvantages of LDPE are low tensile strength, puncture and tear resistance with high stiffness.

Linear low density polyethylene (LLDPE) is a transparent material. It has more side branches than LDPE but comparatively short. LLDPE qualities are high strength and stiffness, puncture and tear resistance, and excellence low temperature toughness. LLDPE is used in various film applications such as food packaging.

## **1.4 Properties of polyethylene**

### **1.4.1 Density**

Density of PE depends on polymerization process and its thermal history. Density can significantly influence PE properties. 100% crystalline PE sample would have density of  $1\text{ g/cm}^3$  while the density of 100% amorphous samples is  $0.85\text{ g/cm}^3$ . The typical density value are  $0.92\text{-}0.95\text{ g/cm}^3$  for LLDPE.  $0.91\text{-}0.94\text{ g/cm}^3$  for LDPE and  $0.95\text{-}0.96\text{ g/cm}^3$  for HDPE. (Vasile, Cornelia 2005).

### **1.4.2 Crystallinity**

PE is described as a semi-crystalline polymer. The properties of PE depend on its crystalline content. Crystallinity in PE is primarily a function of number of branches present in the skeletal chains. As more branches are present in the skeletal chains, crystallinity decrease significantly. The crystallinity may vary from about 35 to 75%. Low crystallinity may offers good processability, better transparency and economical melt processing. (Price, 1997).

Crystallization first begins from a nucleus and once nucleated proceed with the growth of folded chain ribbon-like crystallites called lamellae (see figure 1.1). Lamellae have various sizes and imperfections that include planar zig-zag of crystalline PE chains. Lamellae are connected by “tie molecules”, leading to tougher structures. (see figure 1.2).

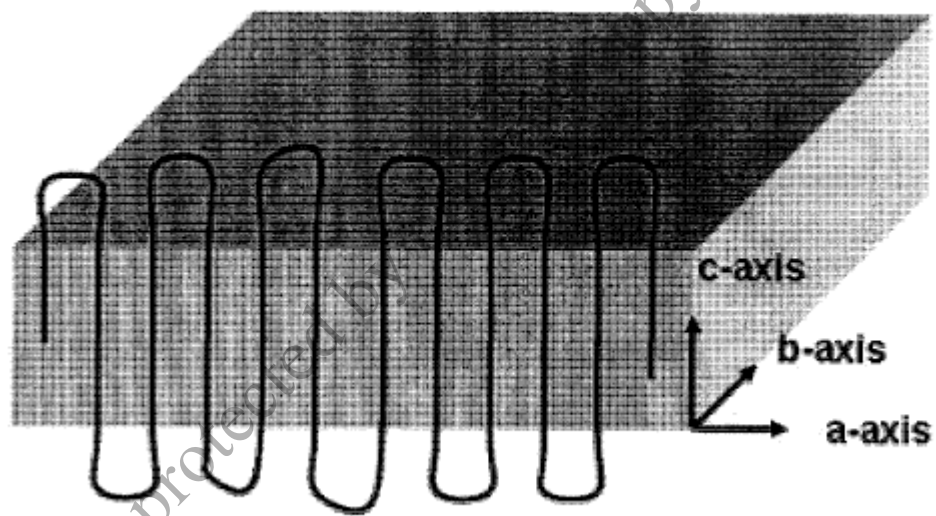


Figure 1.1: Schematic of lamella (Liu et al.2003)

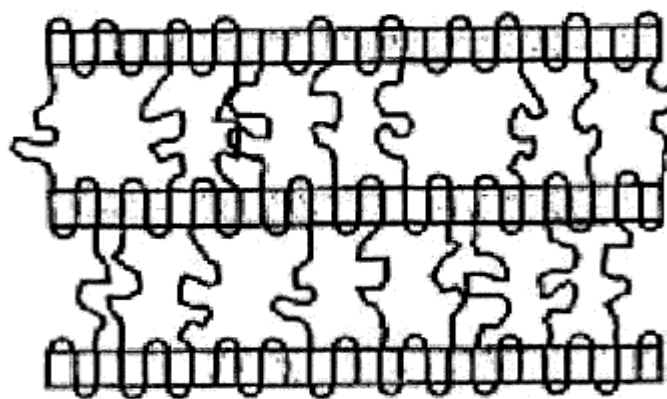


Figure 1.2: Schematic of lamella connected by tie molecules (Liu et al.2003)

### **1.4.3 Mechanical properties**

The presence of a crystalline phase enables PE to retain its mechanical strength over a wide range of temperatures. Tear strength and dart impact strength are mechanical properties that are particularly important in terms of practical applications. The tear strength decreases with increasing temperature and increases with increasing density, as does an increase in molecular weight. Impact strength can be defined as the amount of energy that PE can take up before some permanent damage is done. The impact strength increases rapidly with molecular weight. (Mark, H.F. et al., 1967).

The impact strength of material depends on the inherent molecular structure of the grade used and the morphology arising from the processing conditions. Impact strength also increases with molecular weight, and with co-monomer content up to a certain limit. A significant reduction in the dart impact strength as well as the tear strength with increasing long-chain branching (LCB) is observed for various PE. An increase in LCB level results in lower impact strength and tear strength of blown films. (Ward, I.M. et al., 2004).

### **1.5 Introduction to Fourier Transform Infra Red (FTIR)**

Infrared spectroscopy is performed in order to study the interaction of infrared light with substance. Light is composed of electric and magnetic waves, which vibrate in a plane that is perpendicular to each other. In general, it is an electric wave of light or called the electric vector that interacts with molecules.

Fourier transform infrared (FTIR) spectroscopy was developed from Michelson interferometer which was invented in 1880 by Albert Abraham Michelson. With the development of technology, FTIR has been combined with other equipment to analyze complex mixture quickly and accurately. The number of established techniques is constantly growing, making FTIR more and more useful. (Low and Freeman, 1967).

The performance of any Infrared spectrometer is determined by measuring its signal to noise ratio (SNR). SNR is calculated by measuring the peak height of a feature in an infrared spectrum, such as a sample absorbance peak, and it's divided by the level of noise of some baseline point nearby in the spectrum. There are two advantages of FTIR. The first is the throughput advantage since all the infrared radiation passes through the samples and strikes the detector at once in FTIR. So, it maximizes the amount of light that can be detected during one scan. The second advantage of FTIR is called the multiplex advantage. This means that all the wave numbers of light are detected at once and the noise of particular wave numbers is proportional to the square root of the time spent observing that number.

### **1.5.1 Infrared Spectra**

All objects at a temperature above absolute zero give off infrared radiation. When substance absorbs infrared radiation, chemical bonds in the material would vibrate. Some type of the functional groups tends to absorb infrared radiation in the same wave number range such as frequency range regardless of the structure of the

rest of the molecules. The infrared absorption of carbonyl group ( i.e C=O) occurs at  $1700\text{ cm}^{-1}$  in many different types of molecules. This means that wavenumbers at which a molecule absorbs infrared radiation indicate the presence of certain functional groups in such a molecule.

A plot of measured infrared radiation intensity versus wavenumber is known as an infrared spectrum. Most modern infrared spectra are plotted with wavenumber on the x-axis with high wavenumber on the left while low wavenumber on the right, and the y-axis is plotted in absorbance, which is defined as:

$$A = \log(I_0/I) \quad \text{Eqn 1.1}$$

where

A = absorbance

I = light intensity with a sample in the infrared beam (sample spectrum)

$I_0$  = light intensity measured with no sample in the infrared beam (background spectrum)

The  $I_0$  in Equation 1.3 is the background spectrum that is measured before measuring the sample spectrum in an FTIR.  $I_0$  measures the contribution of the spectrometer and the environment to a spectrum. The parameter I contains contribution both from the instrument, environment and sample. So the ratio of  $I_0$  to I can cancel the instrument and environment contributions and only retain sample's spectrum.