FABRICATION OF CARBON BRUSH BY USING PALM OIL SHELL FOR RAILWAY APPLICATION

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For my beloved mother and father
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Thank you.
ABSTRACT

Carbon brush is a small block made of mostly carbon and graphite which is used as a current transmitter between stationary and moving part of electric generator or motor. Carbon brush is typically produced by using mineral graphite which is an allotropic form of carbon as the raw material beside the addition of fillers such as copper in order to enhance the mechanical ability of the carbon brush. In order to achieve a sustainable environment and good natural resources management for the future generation, the usage of graphite from natural resources for the fabrication of the carbon brush need to be reduce. This research is conducted in order to minimize the usage of the graphite as the raw material by replacing it with carbon from palm oil shell for the fabrication of carbon brush for railway application (Light Rail Transit). This study also intended to investigate the properties differences of the carbon brushes by preparing it with several compositions and compared it with the commercial carbon brush. In obtaining the carbon precursor, the palm oil shells were prepared at 400°C, 500°C and 600°C. The carbon brush samples were prepared with the combination of carbon, copper, polyethylene glycol and phenolic resin at four different ratios. The mixture were then shaped into cylindrical shape and sintered at 800°C in tube furnace for an hour. The results show that sample type 45C 35Cu posses the best mechanical properties in term of hardness and conductivity compared to the others. For conductivity properties of the carbon brush, copper powder usage were essential as it will provide good conductivity which were proven where the highest conductivity were achieved for sample 45C 35Cu which is 84.91x10⁻³ siemens per cm. Hardness of 45C 35Cu samples were recorded to be at 50.67 duro which lead to the lowest wear rate which is 0.004 g/min.
ABSTRAK

Berus karbon adalah komponen blok kecil yang diperbuat daripada karbon dan grafit yang digunakan sebagai penghubung antara komponen statik dan komponen yang berputar yang merupakan sebahagian daripada penjana elektrik atau motor. Berus karbon biasanya dihasilkan dengan menggunakan mineral grafit sebagai bahan mentah di samping penambahan bahan tambah seperti tembaga untuk meningkatkan keupayaaan mekanikal berus karbon. Untuk mencapai persekitaran yang mampun dan pengurusan sumber semula jadi yang baik untuk generasi akan datang, penggunaan grafit daripada sumber semula jadi untuk fabrikasi berus karbon perlu dikurangkan. Kajian ini dijalankan bertujuan untuk mengurangkan penggunaan grafit sebagai bahan mentah dengan menggantikannya dengan karbon yang terhasil daripada tempurung kelapa sawit untuk fabrikasi berus karbon bagi penggunaannya dalam kereta api (Kereta api ringan). Kajian ini juga bertujuan untuk menyelidik perbezaan sifat berus karbon dengan menyediakan dengan beberapa komposisi yang berbeza dan dibandingkan dengan berus karbon komersial. Dalam memperoleh pelopor karbon, tempurung kelapa sawit telah dibakar pada suhu 400°C, 500°C dan 600°C. Sampel berus karbon telah disediakan dengan gabungan karbon, tembaga, polyethylene glycol dan resin fenolik dengan campuran empat nisbah yang berbeza. Campuran ini kemudiannya dibentuk menjadi bentuk silinder dan dibakar pada suhu 800 °C dalam tiub relau selama satu jam. Keputusan menunjukkan bahawa jenis sampel 45C 35Cu memiliki sifat-sifat mekanikal yang terbaik dari segi kekerasan dan kekondusksian berbanding dengan yang lain. Bagi nilai kekondusksian berus karbon, penggunaan serbuk tembaga adalah penting kerana ia akan menghasilkan kekondusksian yang baik yang telah terbukti di mana kekondusksian tertinggi dicapai bagi sampel 45C 35Cu ialah 84.91x10-3 siemens per cm. Kekerasan
sampel jenis 45C 35Cu dicatatkan berada pada tahap 50.67 duro yang menghasilkan kadar haus rendah bagi berus karboniaitu 0.004 g / min.
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CHAPTER 1

INTRODUCTION

1.0 Introduction

Carbon brush is a small block made of mostly carbon and graphite which is used as a current transmitter between stationary and moving part of electric generator or motor. There are many applications of carbon brushes where it is designed to reduce severe damage when there is an electrical contact for direct current devices. Normally, carbon brushes are used in railways, automobiles and dynamos. Carbon brush is typically produced by using mineral graphite which is an allotropic form of carbon as the raw material beside the usage of charcoal. The important key point in producing a good electrical carbon brushes is that it should require a very good frictional characteristics along with a high to moderate conductivity. This study is proposing on fabricating carbon brushes by using palm oil shell (OPS) as a carbon pre-cursor. The aim of proposing palm oil shell as raw material to produce carbon precursor is one of the alternative rather than the usage of natural resources such as graphite and charcoal.

Raw material that are generally used for the production of activated carbon are those with high carbon but inorganic contents such as wood, lignite, peat and coal (Lua & Guo, 2001) and palm oil shell is a good replacement for the carbon brush’s raw material due to several reasons as it has a high considerable carbon content which is about 55.7% compared to the other material such as oil palm fiber which the carbon
content is about 49.6% and sugarcane bagasse 53.1% (Rincon & Gomez, 2012). Other than that, the cost to get the palm oil shell is relatively low, because it is treated as a waste material which gives benefit in many ways. According to Department of Statistic of Malaysia, Statistic of Oil Palm, Coconut, Tea and Cocoa (1981), there are about 1.44 million tons of palm oil shell that being estimated being end up as a waste material thus, it is an advantages to the oil palm industry if the shell could be transform into something useful. The basic production of carbon brushes in industries are involving four main operation which are shearing, finishing, assembling and testing. In this study, several processes such as crushing, milling, mixing, carbonization and compaction are used to produce the carbon brush

1.1 Problem statement

Usually the carbon brush that imported from overseas are made from charcoal or graphite and the continuity of the usage will lead to the reduction of the natural resources. Sustainable environment and natural resources management need to be highlighted nowadays in order to ensure that the future generation would be able to access the same resources as us. Other than that, palm oil shell is known as one of the material that contains high contents of carbon but they are being treated as a waste material. Major disposal problems have arise due to the presences of the waste from palm oil industries where they been stockpiled and dumped which caused the storage problems in the vicinity of the factories as they were produced everyday (Alexander & Mindness, 2005). This is such a devastate issues because we could be able to minimize the cost in obtaining the main material for carbon brush production and also reduce and reuse the waste material. In order to utilize the oil palm waste, the productions of carbon molecular sieve (CMS) from palm oil shell were widely used by other than activated carbon (Abdullah, 2013). In order to ensure the responsibility is being held, this study is undertaken as an alternative way to find the best methods and composition that can utilize the environmental friendly material (palm oil shell) as a substituent for the material used in the fabrication of the carbon brush that are currently used in Malaysia.
1.2 Objectives of study

The aim of the studies is to produce carbon brushes using carbon formed from local agricultural waste which is palm oil shell. To achieve these, a study has been carried out with the following objectives:

1) To investigate the effect of carbonization temperature on the palm oil shell
2) To investigate the effect of different composition of copper powder on the sample prepared.
3) To compare the properties result of fabricated carbon brush with the commercial carbon brush used in the industry (RapidKL Light Rail Transit).

1.3 Scope of study

The scope of this study is as follows:
1) Preparation of carbon pre cursor from palm oil shell using drying, crushing, and sieving and heat treatment method.
2) Carbonization of carbon precursor at different temperature (400°C, 500°C and 600°C)
3) Fabrication of carbon brush by using different percentage of filler (copper powder) at (0%, 10%, 22.5% and 35%).
4) Characterization of the carbon brush samples by using SEM (Scanning Electron Microscopy) and Fourier Transform Infrared (FTIR)
5) Density and porosity, conductivity and resistivity, hardness and wear rate determination of the carbon brush samples.
6) Industrial carbon brush used in comparison with the prepared carbon brush is from RapidKL Light Rail Transit (E50X).
CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter is discussing the details on the carbon brush, types of carbon brushes and the fabrication process of the carbon brushes. Discussion on palm oil, palm oil shell and how carbons were produced from the shell were also stated in this chapter. Carbon brush is used in electric motor or generator to transmit electrical current from a static to the rotating part by charging an electromagnet on an axle. The carbon brush is placed adjacent to and in contact with the commutator where commutator is basically a ring which is placed around the axle. The commutator will spin as the axle is spinning and the carbon brushes will constantly maintaining the contact against the commutator. The electrical current will flow from the electrical sources through the brushes to the commutator, and from the commutator to the electromagnet in the axle (Belt, 1954). Because of the sliding contact, brushes play an important role in transmitting the electric current between the stationary and the rotary part.

A carbon brush is normally built of carbon with an amorphous structure or graphite which is an allotropic form of carbon where it is used to run the electric current and sliding on the commutator of the motor or the rotating slip ring of the generator. These electrical contact elements are generally compounded by mixing fine solid carbon with binder and subjecting them to heat and pressure to compact the material. Electrical
brushes and brush materials require a very good frictional characteristic combined with high to moderate conductivity. Carbon brush is widely used in automotive area, consumer products, industrial area and public transport market where all the carbon brushes are differ with each other. Carbon brush that normally used in railway application is as shown in Figure 2.1.

![Figure 2.1: Carbon brush (Morgan, 2016)](image)

### 2.1.1 Type of Carbon Brush

There are several types of carbon brush in industry as they were fabricated according to different objective to achieve and improve the reliability in motors and generators as shown in Table 2.1 below. Type of carbon brush is dependently of material usage.

<table>
<thead>
<tr>
<th>NO</th>
<th>FIGURE</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><img src="image" alt="Solid brush" /></td>
<td>Solid brush is the simplest type of brush that being used on machines with no electrical and mechanical problems and they are relatively heavy.</td>
</tr>
<tr>
<td>NO</td>
<td>FIGURE</td>
<td>TYPE</td>
</tr>
<tr>
<td>----</td>
<td>--------</td>
<td>------</td>
</tr>
<tr>
<td>2</td>
<td><img src="image1" alt="Split brushes" /></td>
<td><strong>Split brushes</strong>&lt;br&gt;• Split brushes are formed by assembling two, three or more carbon sections into one unit.&lt;br&gt;• The splitting of the brush produce a large area for electrical contact points between the brush surface and the commutator.&lt;br&gt;• This splitting increase the resistance in the transverse circuit of the brush and enables better dynamic properties.</td>
</tr>
<tr>
<td>3</td>
<td><img src="image2" alt="Spread brushes" /></td>
<td><strong>Spread brushes</strong>&lt;br&gt;• A special type of split brush where the tops part of both sections is chamfered at a certain angle towards their dividing line is known as spread brush.&lt;br&gt;• The top piece with a chamfered bottom face will support the applied pressure to the brush where they are generally made from brush or insulation material that has a cushioning effect.</td>
</tr>
<tr>
<td>4</td>
<td><img src="image3" alt="Tandem brushes" /></td>
<td><strong>Tandem brushes</strong>&lt;br&gt;• Tandem brushes are special pairs of brushes, where each brush has its own box within the tandem brush holder, pressed against the commutator by separate pressure fingers.&lt;br&gt;• The result is a symmetrical brush pressure and current distribution.</td>
</tr>
<tr>
<td>5</td>
<td><img src="image4" alt="Sandwich brushes" /></td>
<td><strong>Sandwich brushes</strong>&lt;br&gt;• Sandwich brushes are manufacture by bonding together the segments of split brushes where the bonding layer can be an insulating material.&lt;br&gt;• Through the mechanical point of view, sandwich brushes are basically solid brush with an additional polishing effect caused by the bonding layer.&lt;br&gt;• From an electrical point of view, the brush has an increased cross resistance.</td>
</tr>
<tr>
<td>6</td>
<td><img src="image5" alt="Carbon brushes with wear sensor" /></td>
<td><strong>Carbon brushes with wear sensor</strong>&lt;br&gt;• When the wear limit is reached and enables lower maintenance supervision, carbon brushes with wear sensors signal is needed.&lt;br&gt;• Insulated sensor cable is glued in the carbon brush and the warning will occurs when the insulation of the contact is worn down through the wear of the carbon brush.&lt;br&gt;• The warning is electrically evaluated and optically and acoustically recorded</td>
</tr>
</tbody>
</table>
2.1.2 Components in carbon brush

Carbon brush consist of several components which are known as terminal, shunt, shunt location, pad, multi section, markings, bevel, brush face. The part of the carbon brush and its description are described in Figure 2.2 and Table 2.2.

Figure 2.2: Components of carbon brush (Helwig, 2013)

Table 2.2: Description of carbon brush components (Helwig, 2013)

<table>
<thead>
<tr>
<th>No</th>
<th>Component</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Terminal</td>
<td>A device that allow a suitable stationary electrical connection at the end of the wire of a carbon brush</td>
</tr>
<tr>
<td>2</td>
<td>Shunt</td>
<td>A wire that connect the block of carbon to the terminal</td>
</tr>
<tr>
<td>3</td>
<td>Shunt location</td>
<td>The location where the wire were connected to the carbon block</td>
</tr>
<tr>
<td>4</td>
<td>Pad</td>
<td>Mixture of hard plastic and rubber that being glued at the top of the carbon brush as the holder for multiple brush sections that absorb excess vibration</td>
</tr>
<tr>
<td>5</td>
<td>Multi section</td>
<td>Where two or more wafers come together and form the whole brush</td>
</tr>
<tr>
<td>6</td>
<td>Marking</td>
<td>Label of company</td>
</tr>
<tr>
<td>7</td>
<td>Bevel</td>
<td>The 0-45 degree slant cut of the brush on top or bottom of the brush</td>
</tr>
<tr>
<td>8</td>
<td>Brush Face</td>
<td>Surface of the carbon brush which touches the commutator or the ring and become the indicator to determine the brush performance.</td>
</tr>
</tbody>
</table>
2.1.3 Classification and characteristic of carbon brush material

In order to produce a good carbon brush, the selection of suitable carbon grade is the major factor where lesser wearing issues on the commutator can be achieved. The carbon brush can be classified according to their manufacturing processes and the type of the carbons and other ingredient used. There are four main brush grades which are carbon graphite, electro graphite, graphite and metal graphite.

1) Carbon graphite

Carbon graphite is a high strength material with a pronounced cleaning action. This type of brush are normally limited to a lower current density (7 amps/cm²) and used for a slower speed machine with approximately 20.3m/sec (Helwig, 2013). By using this type of material, the brushes could commutate well due to the high resistance and good polishing action generated. Carbon graphite brushes can withstand both high temperature and variable load due to the high temperature treatment.

2) Electro graphite

This type of brush were baked at temperatures of 2400°C which had changes the material physically to a more graphitic structure where density, strength, hardness and resistivity of this brush can be controlled through the raw material composition and processing which help in achieving a better commutating capability with long life (Morgan, 2014). Electro graphitic materials are fairly porous which allow treatment with both organic resins and inorganic materials which increase the life duration at high operating temperature and low humidity (Helwig, 2013). The main application of electro graphite brush is for all DC stationary or traction industrial machines that operate with low, medium or high voltage. Current density for electro graphite brushes under steady conditions is between 8 to 12 A/cm² meanwhile under peak loads, the current density recorded is between 20 to 25A/cm².
3) Graphite
Graphite brush are composed by using natural or artificial graphite combined with resin where natural graphite brush usually contain ash which gives the brushes an abrasive action meanwhile fro artificial brushes, it does not contain ash and it doesn’t have the flaky structure as the natural graphite. For graphite brushes, they were known with their controlled filming and excellent riding qualities for both commutators and slip rings. The operating limitation of the current density for the graphite brushes is in between 10 to 13 A/cm² (Mersen, 2016).

4) Metal graphite
Carbon brush is an important component that allows the electric current transmission between the stationary and rotating parts by sliding contact. This type of brush was manufactured by mixing the graphite with resin and metal powder. Copper is the most widely used metal in carbon brush manufacturing (Morgan, 2014). The mixture will then be pressed and polymerized under an inert temperature. Metal graphite brush is a dense carbon brush with low friction and very low contact drop therefore it operates with very low losses and high currents.

2.1.4 Carbon brush used in Railway Application

Electrification system in railway application can be categorized into voltage, current and contact system. There are several voltage used for railway application which are 750 V DC, 1.5 kV DC, 3 kV DC, 15 kV AC and 25 kV AC where the voltage differences affecting the speed of the train. Low voltages are suitable for low speed train with smaller size of coaches. Current flow for railway application could be either alternating current (AC) or direct current (DC). For a railway electrification system, a train must be able to operate at variable speed where this is only practical with DC traction motor where the speed could be controlled by connecting traction motors in various series and parallel combination. The electric current was transferred into the traction motor by contact system which is the third rail or overhead wire. For low voltage supply which is
less than 1 kV DC, the contact system normally use are third rail meanwhile overhead wire are used for higher voltage current flow.

Carbon brushes work as a component that create an electrical contact to the rotating component of a machine through sliding rings or collectors in the traction motor. In railway applications, carbon brush sliding contacts are particularly in demand which include short overloading, large current peaks, longer idling, weak load operation, aggressive gases and vapours, high ambient temperatures, oil mists and high ambient dust and ash content (Schunk, 2009). The carbon brushes are located inside the traction motor which is installed at the bogie of a train as in Figure 2.3. Inside the traction motor, the carbon brushes were installed directly proportional to the commutator as shown in Figure 2.4. For RapidKL Light Rail Transit, DC traction motors were used where the voltage flow for the train is 750 V DC. The usage of commutator is compulsory as commutator is used for a DC motor. The relationship of commutator and carbon brush in a traction motor is crucial where the carbon brush should have high wear rate compared to commutator as the maintenance for a carbon brush is easy and more economical compared to the maintenance of the commutator. The properties data of the carbon brush used in the railway application were listed in Table 2.3 according to the type of material used in the fabrication of the carbon brushes.

![Figure 2.3: The traction motor on train bogie](image-url)
Table 2.3: Properties of carbon brush used in railway application (Schunk, 2008)

<table>
<thead>
<tr>
<th>Grade</th>
<th>Material type</th>
<th>Voltage drop</th>
<th>Coefficient of friction</th>
<th>Resistivity, $\mu\Omega$m</th>
<th>Metal content</th>
</tr>
</thead>
<tbody>
<tr>
<td>A125</td>
<td>Copper graphite</td>
<td>v1</td>
<td>l</td>
<td>0.25</td>
<td>90</td>
</tr>
<tr>
<td>B25</td>
<td>Bronze graphite</td>
<td>v1</td>
<td>l</td>
<td>0.3</td>
<td>90</td>
</tr>
<tr>
<td>C16</td>
<td>Metal graphite</td>
<td>l</td>
<td>l</td>
<td>1.0</td>
<td>45</td>
</tr>
<tr>
<td>S11</td>
<td>Silver graphite</td>
<td>v1</td>
<td>m</td>
<td>-</td>
<td>95</td>
</tr>
<tr>
<td>F19</td>
<td>Graphite</td>
<td>m</td>
<td>l</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>F40</td>
<td>Resin bonded graphite</td>
<td>h</td>
<td>l</td>
<td>100</td>
<td>-</td>
</tr>
<tr>
<td>E50X</td>
<td>Electrographite</td>
<td>h</td>
<td>l</td>
<td>100</td>
<td>-</td>
</tr>
</tbody>
</table>

2.2 Carbon

The name of carbon is derived from the Latin word “carbo” which is known as charcoal by the Romanian. Understanding the terminology of carbon is quite complicated as carbon has a diversity material forms which is known as polymorphs (St.Mary, 2013). This material is known as carbon but they have different physical structures which lead to different names such as graphite, diamond, fullerene, amorphous and others. Carbon element is widely found in the environment in a form of compound which is an essential material in the production of synthetic carbon materials. Carbon has the highest melting
point of all elements which is around 3500°C and it is also known as an adsorbent material which affected by the nature of a carbon itself as they develop completes surface structure (Kim, J.M *et al.*, 1999). There are only two carbon polymorphs which are found in the earth as a mineral which are diamond and natural graphite (St.Mary, 2013). Diamond is known as the hardest material in nature and has the highest atomic density of 3.52 g cm⁻³ which indicates the tight bonding of carbon atom (Pierson, 1993). It consists of carbon atom that are tetrahedral bonded that form a three dimensional network. The physical properties of carbon are given by the structure where it has the highest thermal conductivity and the highest melting point.

Graphite is known in ancient times where the natural deposits of graphite are called as black lead, silver lead and plumbago. Graphite is one of the softest materials where it was primarily used as a lubricant and its does occur naturally. The most commercial graphite is produced by treating the petroleum coke which is a black tar that remained after the refinement of the crude oil (Marsh & Rodriguez, 2006). Graphite is one form of carbon which is flexible which can be turned to diamond under a high pressure of 60,000 atm and it will transform back to a more stable graphite phase after being exposed to high temperature of 1200K in an inert atmosphere (Pierson, 1993). The phase and transitional diagram for carbon are shown in Figure 2.5 below where the solid line indicating the equilibrium phases boundaries. At region A, the commercial synthesis of diamond to graphite take places while at region B indicating the P/T threshold of transformation of diamond to graphite. The transformation of graphite to diamond is shown at region C.

![Figure 2.5: The phase diagram for carbon (Jefferson, 2015).](image)
Excellent thermal shock resistance, good strength, and susceptibility to oxidation are the factors that lead to desirability of carbon usage in refractory (Sohn et al., 2011). Carbon is chosen as the main material for carbon brush fabrication as it possessed unique self-lubricating and low coefficient of friction properties which make it become highly abrasion resistant materials. This allows the material to operate for long duration with small commutator wear issues. Carbon offers a stable and excellent electrical conductivity which is enhanced by appropriate selection of material and production process. Other than that, the characteristic of carbon which lead to its suitability for carbon brush fabrication is that it could withstand bad operating situation which it cannot melt where this is important criteria in order to ensure that there are no dangerous situation of fusing or welding to adjacent metal parts.

2.2.1 Structure and Properties of Carbon

The carbon atom is the sixth element on the periodic table where it is composed of six electrons. This material is a unique element as it can assume various forms and structure. Carbon has different physical and chemical properties as the allotropes of the structure vary with each other (Bundy et al., 1994). In understanding the nature of carbon, it is necessary to examine the electronic structure of the carbon atom. There are three main carbon allotropes which are graphite, diamond and fullerene where graphite is a good electric conductor due to the electrons in π bond which can move around throughout the graphite. Each carbon atoms are bond tetrahedrally to four other carbon atoms to form three dimensional lattices in diamond (Bundy et al., 1994). The structure of carbon are designated as (1s²), (2s), (2p₁), (2p₂), (2p₃) when bonded to atoms in molecules electron.

Carbon is a material that soft, dull grey or black and can easily be scratched with fingernail. Carbon as a graphite is burn to form gaseous carbon oxide meanwhile carbon monoxide occur when oxygen supply are restricted. The properties of carbon are shown as stated in Table 2.4.
Table 2.4: Properties of carbon (Kristen, 2005)

<table>
<thead>
<tr>
<th>No.</th>
<th>Properties</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Symbol</td>
<td>C</td>
</tr>
<tr>
<td>2</td>
<td>Atomic number</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>Atomic mass</td>
<td>12.011</td>
</tr>
<tr>
<td>4</td>
<td>Number of protons</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>Number of neurons</td>
<td>6</td>
</tr>
<tr>
<td>6</td>
<td>Number electrons</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>Melting point</td>
<td>3500°C</td>
</tr>
<tr>
<td>8</td>
<td>Boiling point</td>
<td>4827°C</td>
</tr>
<tr>
<td>9</td>
<td>Density</td>
<td>2.62g/cu.cm</td>
</tr>
<tr>
<td>10</td>
<td>Normal phase</td>
<td>Solid</td>
</tr>
<tr>
<td>11</td>
<td>Family</td>
<td>Non metal</td>
</tr>
<tr>
<td>12</td>
<td>Period</td>
<td>2</td>
</tr>
</tbody>
</table>

2.3 Palm oil

Palm oil is one of the two most important vegetable oils in the world’s oil and fat market followed by Soya beans (Yahya, 2010). Palm or the scientific name *elaeisguineensis* is the most productive oil producing plant as there are approximately 10 to 35 tonnes of fresh fruit bunch were produced with one hectare of palm oil trees (MPOB, 2011). In 1870, palm oil was first introduced into Malaysia through Botanic Garden in Singapore while oil palm industry in Malaysia was started in 1917. Through the strategy of diversification and modernization by various industries, palm oil became one of an important asset to the country along with rubber.

The production of palm oil are increasing through the century as it is recorded that only 1.3 million tons of palm oil were produced meanwhile in 2010, approximately 18.60 million tons of oil palm were recorded. This could be achieved as the plantation area is getting bigger to 4.85 million hectares in 2010 (Hartley, 1988). South East Asia is nominated as the dominant production of palm oil with the combination of oil palm production from Malaysia and Indonesia are approximately 83%. Currently, due to the enormous plantation area, Malaysia is being the second leading country in the production and exportation of palm oil as shown in Figure 2.6.
The industry of palm oil is giving huge impact on the economy as well as the environment where they are generating a huge number of products along with residue. Total oil production from the whole oil palm plantation is recorded to be only 10% while the others are end up as the residue. The main residue from the oil palm plant are including oil palm truck (OPT), oil palm fronds (OPF), empty fruit bunches (EFB), and palm pressed fibers (PPF), which include palm shells and palm oil mill effluent palm (POME). The most common residue are the empty fruit bunch which has a high moisture content of approximately 55-65% and high silica content which are about 25% of the total palm fruit bunch (Crutchfield, 2007). The ideal composition of oil palm fruit bunch is as shown in Table 2.5.
Table 2.5: Ideal composition of palm fruit bunch (Keu, 2005)

<table>
<thead>
<tr>
<th>Ideal composition of palm fruit bunch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bunch weight</td>
</tr>
<tr>
<td>Fruit/bunch</td>
</tr>
<tr>
<td>Oil/bunch</td>
</tr>
<tr>
<td>Kernel/bunch</td>
</tr>
<tr>
<td>Mesocarp/bunch</td>
</tr>
<tr>
<td>Mesocarp/fruit</td>
</tr>
<tr>
<td>Kernel/fruit</td>
</tr>
<tr>
<td>Shell/fruit</td>
</tr>
</tbody>
</table>

2.3.1 Palm oil shell

Palm oil shell is one of the high carbonaceous materials in the oil palm plantation residues and it is usually burned in low value resources or discarded in the field where both ways are unfavorable to the environment. One of the advantages of palm oil shell is that it could be used as the precursor in the production of activated carbon. According to Agriculture and Consumer Protection, palm oil shell are also being used as a fuel in a boiler by a cement company in Malaysia and it was found that the level of CO₂ emissions are being reduced by 336.26 thousand metric tons in 2006. The weight of the oil palm fruit bunches are varies from each other’s in range from 10 to 40 kg meanwhile each individual fruit weight are ranging from 6 to 20 grams. The fruit of oil palm are made up of an outer skin (exocarp), a pulp (endocarp) and kernel which contains the oil. The structure of oil palm fruit and fresh fruit are shown in Figure 2.7 and Figure 2.8.

![Figure 2.7: Oil palm fruit (MPOC, 2012)
Palm oil shell has the same characteristic as coconut shells where both have a complex pore structure and fiber matrix where it become the best options for the production of activated carbon. For the production of activated carbon, the selection of endocarp should be thick in order to get the best quality of activated carbon. There are two different types of oil kernel shell which are dura type and tenera type as shown in Figure 2.9. Dura types of palm oil shell are normally having thick endocarps compared to tenera type and it will helps in producing a better quality of activated carbon. The characteristic of Dura oil palm types and Tenera oil palm type are shown in Table 2.6.
Table 2.6: Characteristic of oil palm type (Dit, 2007)

<table>
<thead>
<tr>
<th>Features</th>
<th>Percentage (%)</th>
<th>Dura oil palm type</th>
<th>Tenera oil palm type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mesocarp</td>
<td>20-65%</td>
<td></td>
<td>60-96%</td>
</tr>
<tr>
<td>Shell thickness</td>
<td>20-50%</td>
<td></td>
<td>3-20%</td>
</tr>
<tr>
<td>Seed thickness</td>
<td>4-20%</td>
<td></td>
<td>3-15%</td>
</tr>
</tbody>
</table>

The small physical criteria of palm oil shell helps in carbonization process for mass production which lead to the discovery that the charcoal produce from the palm shell can be pressed into a heat efficient bio-fuel briquette. The huge number of oil palm plantation in Malaysia helps in ensuring the constant stream of raw material for the bio-fuel briquettes and activated carbon are available. The basic composition of palm oil shell is shown in Table 2.7.

Table 2.7: Basic composition of palm oil shell (Farid & Gibbs, 1994)

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Palm oil shell</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximate analysis (wt. %)</td>
<td></td>
</tr>
<tr>
<td>Ash</td>
<td>2.3</td>
</tr>
<tr>
<td>Volatile matter</td>
<td>68.8</td>
</tr>
<tr>
<td>Fixed carbon</td>
<td>20.3</td>
</tr>
<tr>
<td>Ultimate analysis (wt. %)(dry ash)</td>
<td></td>
</tr>
<tr>
<td>Carbon</td>
<td>47.62</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>6.2</td>
</tr>
<tr>
<td>Oxygen</td>
<td>43.38</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>0.70</td>
</tr>
<tr>
<td>Moisture (wt. % dry air)</td>
<td>8.40</td>
</tr>
<tr>
<td>Gross caloric value (mg/kg)</td>
<td>19.1</td>
</tr>
<tr>
<td>Average bulk density (kg/m³) &lt;18mm</td>
<td>440</td>
</tr>
</tbody>
</table>

2.4 Fabrication of carbon brush

In order to fabricate carbon brush, there are several components that are needed which are carbon, binder and filler. Carbon is known as a versatile material due to its exceptional properties which enable the designers to produce machines with performance and durability. There are several steps taken in carbon brush fabrication process as shown in Figure 2.10. The first step of carbon brush fabrication is that the material, binder and filler are needed to be selected and mixed together. Then the kneading, pulverizing, sieving and mixing process are taken before the molding process
take part. After the carbon brush being shaped, the heat treatment is taken where the temperature are defined based on the type of material that used to create the brushes. The finishing and inspection process will be taken after the completion of the product to ensure that the carbon brush reach the standard needed.

Figure 2.10: The process of carbon brush fabrication (Toyo Tanso, 2015)
2.3.2 Raw material

In fabricating carbon brushes, graphite are mainly the common raw material used other than charcoal. As the year had passed and lots of study has been taken, there are lots of raw material that can be used to fabricate carbon brush other than graphite and charcoal. In order to reduce the usage of natural resources abruptly, the alternative methods are introduced by producing carbon from organic material. In choosing the raw material that being used in the fabrication of carbon brush, several factors are taken into consideration such as:

1) High carbon content
2) Low in organic content
3) High density and sufficient volatile content
4) The stability of supply in the countries
5) Inexpensive material
6) Low degradation upon storage

2.3.3 Filler

Filler is known as a solid material which is used in order to fill up the cavity or increasing mass of something which capable of changing the physical and chemical properties of materials. According to ASTM C 859, filler is an inert material under the conditions of use which are needed in order to fill up spaces while increasing the physical properties. From the first edition of this handbook, filler are classified according to groups of materials such as minerals, glass, organic materials, fibers, carbon black and metal but some improvement has been taken as study have proven that they are more beneficial if classification are arranged according to the particle size as particle size affects the performance of the filler itself (Wypych, 2010).
In filler application, there are eight important characteristic that affect the resultant material which are as follows:

1) Particle size and distribution
2) Aspect ratio
3) Chemical composition of surface
4) Mechanical properties of filler particle
5) Electrical and thermal conductivity
6) Quantitative description of interactions
7) Composition of admixtures
8) Optical properties

Filler is needed in carbon brush fabrication due to the ability of electrical connection between the carbonaceous materials with the metal powder other than increasing the density, strength and hence wear-life of the carbon brushes. There are several types of filler which are commonly used in carbon brush fabrication such as:

Table 2.8: Type of filler used in carbon brush

<table>
<thead>
<tr>
<th>No</th>
<th>Type</th>
<th>Explanation</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Copper</td>
<td>Copper is a pure metal or metal alloy with high thermal and electrical conductivity. Copper is normally used as a conductor of heat and electricity, a building material and a constituent of various metal alloys. Copper is usually used in its unalloyed form as it has better conductivity compared to copper alloy. In carbon brush application, carbon-copper mixture are producing high electrical conductivity and good wear resistance which are an important aspect in carbon brush fabrication.</td>
<td>(Campbell, 2008)</td>
</tr>
<tr>
<td>2</td>
<td>Silicon Carbide</td>
<td>Silicon Carbide is a material that being produced through solid state reaction between sand (silicon dioxide) and petroleum coke (carbon) at high temperature. This material has the ability to run electric current through the mixture of clay and carbon. Silicon Carbide is a material that being added in carbon brush fabrication to increase the service life. The disadvantages of silicon carbide powder are that it reduces the efficiency of the motor.</td>
<td>(Rashed, 2002)</td>
</tr>
<tr>
<td>4</td>
<td>Zinc</td>
<td>Zinc is the fourth most highly used metal in industry where zinc as mostly used as the corrosion protection. Zinc is a non-toxicity material with low melting point and low hardness of the oxide. The thermal conductivity for zinc is 73 W/m.K^{-1}</td>
<td>(Campbell, 2008)</td>
</tr>
</tbody>
</table>
2.3.4 Binder

Binder is the material that has the ability to bond all the material of carbon brushes. Other than the bonding properties of a binder, insulation of a binder helps in producing high resistivity which leads to good commutation ability that suit high speed motors. Binder is generally used in the fabrication of carbon brush with low metal content where a medium and high metal content carbon brush are tends to be able in relying on their bond upon binder. In choosing the binder for carbon brush fabrication, there are several criteria that need to be rely on such as below (Holl & Martin, 1976):

1. The binder must possess good pouring traits and should be able in powder structure.
2. A binder material should have exact and adequately high melting point where it can be easily soften and have a little viscosity.
3. When the binder is exposed to high temperature, its melted state should be able to wet the raw material to a quality that could leads to a high mechanical stability.
4. When it is heated in air, it should be cure by cross-linking method.
5. Good filler should be able to provide the brush with a good abrasion characteristic.

At the early year in carbon brush history, the binder used in the fabrication process is sugar followed by pitch where this material is not suitable for high speed motor. Through the development and studies that have been taken, it proved that resin is the best option that could match well with the motors. Resin binder is normally used for carbon brush that composed of carbon material, solid lubricant, resin binder and additive. In order to increase the strength of the carbon brush, different resins that are being subjected to different temperature is tested in the fabrication of the carbon brush. The resins that are employed in this purposed are glycerol-phthalate, the vinyl resins, cellulose esters and phenolic resins. Nevertheless, the listed resins except than phenolic resin is thermoplastic where they tend to flows when the temperature increases which lead to their unsuitability as a binder in carbon brush fabrication. Table 2.9 shows the type of binders that are commonly used in the fabrication of carbon brushes.
Table 2.9: Type of binder used in carbon brush

<table>
<thead>
<tr>
<th>No</th>
<th>Type</th>
<th>Explanation</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pitch</td>
<td>Pitch is an organic compound that has a distinct aromatic structure. Pitch is proven to be a good binder and will reduce to carbon at high temperature. It is the distillation residue of coal tar where it is produced form selected or thermally processed raw tar according to their application purposes.</td>
<td>(Lewis, 1997)</td>
</tr>
<tr>
<td>2</td>
<td>Phenolic resin</td>
<td>Phenolic resin is a material that has a relatively high to very high specific direct axis resistance, which positively affects service life and radio interference suppression during fast processes of commutation and very high peripheral speeds. Phenolic resin has generally a noticeably lower density than phenolic resin. Phenolic resins can be additionally impregnated in order to improve the mechanical run performance. Furthermore phenolic resin display better mechanical vibration damping characteristics and are particularly suitable for high peripheral speeds and larger electrical loads.</td>
<td>(Schunck Group, 2008)</td>
</tr>
<tr>
<td>3</td>
<td>Polyethylene glycol</td>
<td>Polyethylene glycol is an addition polymer of ethylene oxide and water where it is freely soluble in water with a molecular weight more than 1000. It is also act as a binder which is used for fibers such as wood pulp fiber and for adhering superabsorbent particulate materials to the fibers. Other than that, PEG is normally used as a binder for tablet from industrial manufacturing to medicine. By inclusion of PEG, the sample could form into solid tablet and handling process is becoming easier. The melting point for PEG is different according to their type.</td>
<td>(Chen et al., 2004)</td>
</tr>
</tbody>
</table>

2.3.5 Fabrication of carbon brushes from other research

Carbon brushes could be fabricated from different types of materials and methods in order to ensure that the main purposes of the carbon brushes could be achieved. Table 2.10 is summarizing the materials and methods used in preparing the carbon brushes based on previous studies that have been taken.
<table>
<thead>
<tr>
<th>No</th>
<th>Raw material</th>
<th>Additives/lubricants</th>
<th>Binder</th>
<th>Method</th>
<th>Discussion</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Graphite</td>
<td>Molybdenum disulfide</td>
<td>Thermosetting resin</td>
<td>Mixing</td>
<td>Four type of samples with different percentage of MoS₂ (0%, 2%, 4% and 6%)</td>
<td>Hu, Chen, Xia, &amp; Ding, (2008)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Phenolic Resin</td>
<td>Tabletting</td>
<td>Relative humidity set at 10% and 50%</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Drying</td>
<td>Presence of MoS₂ in the mixture forms a layer of sulfur on the surface which reduces the wear rate in low humidity environment.</td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Milling</td>
<td>High percentage of MoS₂ reduces the wear rate of the brushes.</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sizing</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Molding</td>
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<td></td>
<td></td>
<td></td>
<td>Curing</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Machining</td>
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<td></td>
<td>Finished brush</td>
<td></td>
<td></td>
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<tr>
<td>2</td>
<td>Carbon (OKPS)</td>
<td>Copper</td>
<td>Epoxy Resin</td>
<td>Crushing</td>
<td>Different particle size of carbon tested (&lt;90μm and &lt;150μm)</td>
<td>Ibrahim, Abdul Razak, Selamat, &amp; Mustafa, (2015)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sieving</td>
<td>Hardness: Samples with particle size (&lt;150μm) better than sample particle size (&lt;90μm)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Mixing</td>
<td>Resistivity: Samples with particle size (&lt;150μm) better than sample particle size (&lt;90μm)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Compaction</td>
<td>Friction and wear: Samples with particle size (&lt;150μm) better than sample particle size (&lt;90μm)</td>
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<td></td>
<td>Post baking</td>
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<td></td>
<td></td>
<td></td>
<td>Finished brush</td>
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<tr>
<td>3</td>
<td>Graphite</td>
<td>Copper</td>
<td>Phenolic resin</td>
<td>Heating</td>
<td>Different amount of C-Cu composition used (10/90, 20/80, 30/70, 40/60, 50/50, 60/40, 70/30, 80/20).</td>
<td>Mohammed, Ibrahim, &amp; Hussain, (2009)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Molybdenum disulfide</td>
<td></td>
<td>Sieving</td>
<td>Maximum hardness achieved at 30% Cu. Hardness decrease as Cu content increase due to the softness of copper.</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Mixing</td>
<td>Resistivity decrease as Cu content increase due to high electrical conductivity of copper.</td>
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<td></td>
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<td></td>
<td>Pressing</td>
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<td>Curing</td>
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<td></td>
<td>Finished brush</td>
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</tbody>
</table>
REFERENCES


Foreign Agricultural Service- Commodity Intelligence Report (2007). Indonesia: Palm Oil Production Prospects Continue to Grow. United State Department of Agricultural-USDA


