FRICTION AND WEAR PROPERTIES OF POLYMER COMPOSITE MATRIX MADE BY TAPIOCA STARCH

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A report submitted
in fulfillment of the requirements for the degree of
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DECLARATION

"I hereby declared that this report entitle "Friction and Wear Properties of Polymer Composite Matrix Made by Tapioca Starch" is the result of my own work except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree."

Signature : …………………………...

Name : Siti Norshamimi bt Dollah

Date : …………………………..

APPROVAL

“I hereby declared that I have read through this report entitle “Friction and Wear Properties of Polymer Composite Matrix Made by Tapioca Starch” and found that it has comply the partial fulfilment for awarding the degree of Bachelor of Mechanical Engineering with honours”

Signature : ……………………………………..

Supervisor’s Name : Dr Mohd Rody Bin Mohamad Zin

Date : …...

DEDICATION

To my beloved father and mother.

ABSTRACT

The main purpose of the study is to investigate the friction and wear properties of polymer matrix composite made by tapioca starch as well as to prepare and characterized them at different starch percentage. Polypropylene (PP) mixed tapioca starch were prepared using Hot Press Machine in various weight percentage concentrations ranging from 0%, 10%, 20% and 30% of starch filler. The results from the sample preparation shows that the colour of sample formed is lighter as the starch percentage increased. Then the mechanical properties such as hardness and roughness properties were determined by using Shore Durometer and Hand-held Roughness Tester respectively. Both hardness and roughness properties were found to increase linearly with increasing starch concentration up to 30 wt%. The presence of tapioca starch in PP was found to have positive effect to the hardness and roughness properties. Next, the tribology properties of coefficient of friction (COF) and wear rate were determined with a computerized pin-on-disc wear and friction tester at dry sliding condition. 3D Non-Contact Profilometer also were used to measure the wear scar diameter and wear depth. It was observed that higher starch percentage in PP, lowered the average COF of the composite under dry conditions however the COF increased rapidly at 30 wt% of starch. As for specific wear rate, the result cames up to decreased when the starch percentage increased. Microstructure analysis has been utilized to support the discussion of the output. The results showed that, the addition of tapioca starch into PP matrix increased the wear resistance by decreasing the wear rate by 14.17% and reduced the COF by 20.67%.

ABSTRAK

Tujuan utama kajian ini ialah untuk mengkaji sifat geseran dan kehausan komposit matrik polimer yang dibuat daripada kanji ubi kayu selain menyediakan pada peratusan kanji yang berbeza dan mencirikannya. Polypropylene (PP) yang dicampurkan kanji ubi kayu telah disediakan menggunakan Mesin Tekanan Panas dalam peratusan kanji antaranya 0%, 10%, 20% and 30% isi kanji. Hasil daripada penyediaan sampel menunjukkan bahawa warna sampel yang terbentuk akan lebih cerah apabila peratusan kanji meningkat. Kemudian, sifat-sifat mekanik seperti kekerasan dan kekasaran ditentukan dengan menggunakan Shore Durometer dan Penguji Kekasaran Mudah Alih. Kedua-dua sifat ini didapati bertambah secara linear dengan peningkatan peratusan kanji sehingga 30%. Kehadiran kanji ubi dalam PP didapati mempunyai kesan positif terhadap sifat kekerasan dan kekasaran. Seterusnya, sifat tribologi pekali geseran dan kadar kehausan ditentukan dengan menggunakan pin-pada-cakera berkomputer pada keadaan geser kering. Profilometer 3D juga digunakan untuk mengukur diameter parut kehausan dan kedalaman kehausan. Telah diperhatikan bahawa peratusan kanji yang lebih tinggi dalam PP, telah menurunkan purata geseran pada keadaan kering namun geseran meningkat pesat pada 30% berat kanji. Bagi kadar haus, ia menurun apabila peratusan kanji meningkat. Analisis mikrostruktur telah digunakan untuk menyokong perbincangan. Keputusan menunjukkan bahawa, penambahan kanji ubi ke dalam matriks PP meningkatkan rintangan haus dengan menurunkan kadar haus sebanyak 14.17% dan mengurangkan geseran sebanyak 20.67%.

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LIST OF ABBREVIATION AND SYMBOLS

PP	-	Polypropylene
PMC	-	Polymer Matrix Composite
&	-	And
m	-	Meters
mm	-	Millimetres
g	-	Gram
cm	-	Centimetre
N	-	Newton
hr	-	Hour
min	-	Minute
sec	-	Second
°C	-	Degree Celcius
psi	-	Pound per Square Inch
%	-	Percentage
rpm	-	Revolution per Minute
in^3	-	Inch Cube
lb	-	Pound
ft	-	Feet
etc	-	Et Cetera
MPa	-	Mega Pasca
i.e	-	in example
wt%	-	Weight Percentage
°	-	Degree

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CHAPTER 1

INTRODUCTION

1.1 Background

As well known, synthetic polymer materials have played an important role and have been extensively used in many applications of all fields for many years. Polypropylene is one of the synthetic polymer and basically they resistant to acids and alkaline plus high in tensile strength. Synthetic polymers basically famous for their high mechanical performances, good barrier properties, good heat seal ability and can be tailored easily (Jamshidian, Tehrany, Imran, Jacquot, & Desobry, 2010). However, unfortunately they are quite expensive. Besides, they are all non-biodegradable and manufactured from non-renewable resources. Thus, man focused on biopolymer that tends to be biodegradability and low cost.

In order to solve the non-biodegradable issues, the demand on biodegradable polymers called biopolymers have raised. The word biodegradable means that the degradation of a polymer in natural environment that includes changes in chemical structure, loss of mechanical and structural properties and finally changing into other compound like water, carbon dioxide, minerals and intermediate products like biomass and humid materials (Jamshidian et al., 2010). Starch is one of the biopolymers or natural polymer and own many compromising properties in developing sustainable materials which are biodegradability, low cost, renewability, natural, environmental friendly and can be modified easily (Lu, Xiao, & Xu, 2009). However, starch itself is sensitive to water and cause the starch to have some limitations. The starch-made materials will swell and deform upon exposure to moisture.

Thus, starch often blended with synthetic polymers to improve its properties, biodegradability and to minimize the usage of synthetic polymer (Siang, 2012).

The study of properties of polymer composites matrix (PMC) is very important. This is because different type of PMCs provides different kind of properties in mechanical behaviour, friction and wear. These situations can be due to various combinations or mixtures, the temperature, types of presence microorganism and also the concentration of blend polymers. Therefore, this study will focus on the blend of polypropylene (PP) and tapioca starch with different concentration to investigate their friction and wear properties. The result of this study will provide the better blend concentration in order to discover friction and wear properties of this type of PMC for future use.

1.2 Problem Statement

Polypropylene is an expensive and a non-biodegradable polymer while starch is lower cost but have it limitations mainly due to the very sensitive to relative humidity and solubility in water. In order to overcome these challenges, several researches have successfully blend the starch with synthetic polymer to improve their mechanical properties. However, there is no yet a research on friction and wear properties of PP blend with tapioca starch. Therefore, the effect of the PP blend with the degradation of tapioca starch on friction and wear behaviour is remains unknown. Thus, this study is focused on PP blend with tapioca starch at different concentrations to achieve desired mechanical properties, friction and wear and to design a lower cost PMC.

1.3 Objectives

The objective of this study are;

i. To investigate the effect of starch concentration in polymer matrix composite (PMC) on friction and wear properties

1.4 Scope

The scope of this study are:

i. The polymer used in this study are tapioca starch and PP only

ii. This study only focus on wear and friction properties of PMC using tapioca starch

iii. The polypropylene blend with tapioca starch at different concentration which are 10%, 20%, 30% starch concentrations and neat PP

iv. The sliding condition for the friction and wear test is under dry condition.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to Polypropylene (PP)

Polypropylene (PP) is one of the types of thermoplastic polymer that is used widely in a range of function such as packaging, textiles, stationary, equipment and automotive components. PP is a synthetic polymer that offers an outstanding physical, mechanical, thermal and chemical properties that not found in other thermoplastic polymers (Pérezr, Rivas, & Rodríguez-Llamazares, 2013). Based on Handbook of Polypropylene and Polypropylene Composites (2^{nd} Edition), during the period from 1974 to 1999, the percentage of usage of PP increased from 7% to 12% by the year. This increasing of PP usage required the production to keep up with the increasing demand. Many years passed yet there is always a research in improving PP itself and its properties so that it can meet up with the increasing demand in market.

PP is produced from olefin or alkene monomers that contain a reactive carbon to carbon double bond. The PP started with a monomers called Propylene thus the final product which consist thousands of Propylene monomers is called Polypropylene. Figure 2.1 shows the molecular structure of PP (Calhoun, 2009).

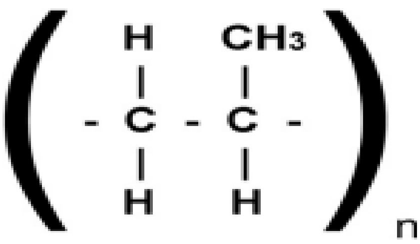

Figure 2.1: Monomer Unit of PP (Calhoun, 2009)

2.1.1 Application of Polypropylene

PP for ages has been developed for many usages over and over again. Now, the major markets for PP are dominated by rigid and flexible packaging which is 37%, followed by automotive compartments, electric and electronic parts and appliances (21%) and textile applications (18%) (Syazwan, 2010).

2.2 Introduction to Starch

Starch is the leading storage component in multiple plants, is important in energy source for developed seedling and is also valuable resources for food and non-food industries due to its exclusive structure-forming behaviours (Molenda et al., 2006). Starch is the natural biopolymers that broadly used to develop environmental-friendly packaging materials to replace petrochemical-base plastic materials. The main source of starch are corn (82%), wheat (8%), potatoes (5%) and cassava derived from tapioca starch (5%) (Kamel & Alwaan, 2018). Figure 2.2 shows the glucose monomer units with two important groups, the –OH and C-O-C bond that made up a starch molecule as a semi-crystalline polymer (sM.K Oduola, 2015).

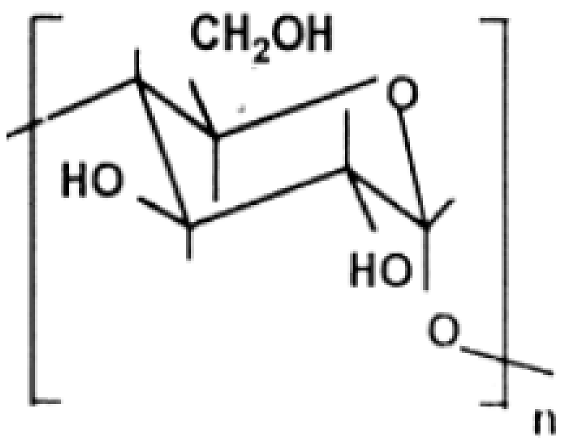

Figure 2.2: Starch Structure (M.K Oduola, 2015)

Starch is not a true thermoplastic but it can transformed into a plastic-like called thermoplastic starch (TPS) (Mitra, 2014). Starch has been received growing attention as promising fillers since the past four decades for its good biodegradability, low cost and renewability (Henry Chinedu Obasi, Ogbobe, & Madufor, 2015). TPS is a renewable and flexible that can be easily used in different 6illime-plastification processes include injection molding, compression molding and extrusion blow molding with equipment used in manufacturing synthetic polymers (Nafchi, Moradpour, Saeidi, & Alias, 2013). According to M.K Oduola (2015), the starch that was mixed with other renewable and non-renewable thermoplastic can have excellent mechanical behaviours and decreased the cost of the materials.

2.3 Introduction to Composite

The composite matrix have been exist since Old Stone age (Elsevier Inc., 2017). Basically composites divided into three types of materials with different performance chemical and mechanically. The composites include Polymer Matrix Composites (PMCs), Ceramic Matrix Composites (CMCs) and Metal Matrix Composites (MMCs). However, this study only discussed on Polymer Matrix Composites (PMCs).

Composite has been defined as a multi-phase system that consisted of two or more matrix components and the reinforcement components. There are three phase of composite materials which are matrix, reinforcement and composite interface. Matrix component is a continuous stage that is included CMC, PMC and MMC by the different matrix materials while reinforcement is a single phase that scattered and surrounded by matrix which is usually fibrous materials (i.e glass fiber, organic fiber and so on)(Wang, Zheng, & Zheng, 2011). Composites interface is defined as an interface between the matrix and reinforcement phase.

2.3.1 Polymer Matrix Composite (PMC)

Generally, PMCs or sometimes called fiber-reinforced plastics are the composites matrix where the matrix is a polymer and the reinforcements or fillers are glass, carbon, boron or natural fibers. Polymer matrix composite (PMC) is a composite materials that contained many fibers that bound together by an organic polymer matrix. The PMC is designed so that the mechanical loads that applied to the material is being supported by reinforcements. The reinforcements in a PMCs provide strength and stiffness that are lacking in matrix while the function of matrix is to bond the fibers together to transfer loads between them (Herrmann, Stieglitz, Brauner, Peters, & Schiebel, 2013).

Polymer composites matrix began almost as soon as man had polymers and they became a part of polymer science and engineering. This is because people could make compositions and actively practise the mixing of every synthetic polymer with every other natural polymer in order to have the substantially and synergistic properties of materials. The properties are greater toughness and impact resistance, higher modulus and higher use temperature (Sperling, 2000). Other advantages of PMCs are their lightweight, high stiffness, high strength, good abrasion and corrosion resistance and also simple fabrication process. This shows excellent strength to wear resistance (Prashanthakuamr & Bhanuprakash, 2017). Thus, the PMCs is designed so that the mechanical loads that subjected in any structure are supported by the reinforcements. There are two major types of polymers used in matrix phase of PMCs which are thermoset and thermoplastics.

Thermoset polymers composed of long chains of molecules that are cross-linked to other chains of molecules included epoxies, polyimides, silicones, vinyl esters and unsaturated polyesters. At room temperature, these polymers can be either liquids or solids and soften when heated and cure (Elsevier Inc., 2017). Thermosets can lower the viscosity which eases wetting (Mitra, 2014). Thermosets, because of their cross-linked structure, tend to have excellent dimensional stability, high-temperature resistance and high resistance to solvents (Herrmann et al., 2013).

Thermoplastic polymers are not cross-linked but composed of long polymer chains that are entangled resulted of monomers units joined together (Askeland and Wright, 2013). Unlike thermoset, thermoplastic soften when heated but then harden again after cooling process. Examples of thermoplastic include polypropylene, polyethylene, polystyrene, poly vinyl chloride (PVC) and polyacetal and etc (Murphy, 1998). Unlike thermosets, thermoplastics are resistance to cracking and impact damage and recently thermoplastics have been developed high performance which have excellent high temperature strength and solvent resistance (Herrmann et al., 2013). Thus these offers thermoplastics a great promise for future manufacturing industry. Figure 2.3 shows the comparison of behaviours of thermosets and thermoplastic matrix.

Resin type	Process temperature	Process time	Use temperature	Solvent resistance	Toughness
Thermoset	Low	High	High	High	Low
Toughened thermoset	↑	↓	↑	↑	↓
Lightly crosslinked thermoplastic					
Thermoplastic	High	Low	Low	Low	High

Figure 2.3: Properties of Thermoset and Thermoplastic Matrix (Herman,2014)

2.3.2 Fiber Reinforcement

Function of reinforcing materials in Fiber Reinforcement Composite (FRC) is to increase the mechanical properties of the resin such as strength and stiffness. Currently, the most important fibers used are glass, aramid and graphite, and the organic fibers include polyethylene also becoming important. Glass fibers are the most widely used for high volume PMC applications since its tensile strength is competitive and cost is lower. The other fibers be used only when the stiffness or weight are at premium because glass has a relatively low stiffness. Natural fiber composite has such properties as low density, good thermal insulation, unlimited availability and low cost. Besides, the machine wear and procession equipment damage for natural fiber is lower compare to conventional synthetic fibers (Singh & Bhaskar, 2013). Thus, natural fiber composite is developed as an alternative to synthetic fiber as reinforcing materials in thermoplastics. Figure 2.4 shows the examples of natural fiber used as reinforcing materials in a composite.

Figure 2.4: Types of Natural Fibers (Udhayasankar & Karthikeyan, 2015)

2.3.3 Characteristic of Composite

Different types of composite materials gave different kind of performance characteristics to the composite materials. The characteristics of composites are depended on the properties of constituent materials and the interaction among them. The shape, size and size distribution of fillers affects the characteristics of the composite. However, despite of the different properties, these composites materials also have some mutual behaviours. Compared to the CMCs and MMCs, PMCs have growing fastest and widely used because of their inherent properties. The characteristic of PMCs are light weight, high impact resistance, good moldability, high specific strength, high specific stiffness, low manufacturing cost, good electrical and thermal insulation, good damping stiffness, good wear resistances and easily pigmented (Elsevier Inc., 2017).

2.4 Application of Polymer Matrix Composite

In composite materials, glass fiber PMCs are the first developed and applied which is in the 1940s where the Americans military radar and air craft fuel tank are produced (Wang et al., 2011). Since then, the PMCs are widely used in a variety of civilian industry and becoming the essential engineering parts. The applications and markets for PMCs are discussed below:

2.4.1 Automotive Industry

Most of the automotive components are not only made from glass and carbon composites, but they also been made from natural fiber composites and nanocomposites such as Mercedes, Volkswagen, Audi Group, BMW, Ford, Opel and Proton (Njuguna, Wambua, & Pielichowski, 2011). The composites materials are mainly used in body parts, engine cover, dashboard, door, sear, fire engine and so on.

According to Rwawiire, Tomkova, Militky, Jabbar, & Madhukar (2015), bark cloth reinforced epoxy composites are suitable materials for interior automotive components since this developed biocomposites had an average strength of 33 Mpa which is higher than the 25 Mpa threshold strength needed for car panels.

2.4.2 Aerospace Industry

The percentage of the composite market for aerospace industry are 14% and was expected to increase over years (Elsevier Inc., 2017). Composites was used in aerospace applications include aircraft, spacecraft, satellites, helicopters, missiles and rockets. According to Elsevier (2017), the characteristics of composites required for aerospace industry are excellent in strength, stiffness and fatigue, and tailor-made design. Carbon, aramid and glass fibers are regularly used due to high requirement.

2.4.3 Building Industry

In construction building, composites commonly used in a large building structure, architectural feature, cooling tower, storage tank, door and window parts, hydraulic constructions and so on. In recent years, the carbon fiber composite has shown a large market as a strengthening and repair for the infrastructures (Wang et al., 2011).

In addition to automotive, aerospace and building industry, the PMCs especially glass fiber composites get wider range of applications in other industries for their price and performances. They also important in the electric and electronic industry, sport equipment, mechanical manufacturing, anti-corrosive equipment and so on.

2.5 Introduction to PP Blend Starch

The important method to improve biodegradability of polymers is by blending and combine the synthetic polymers such as polypropylene, polyethylene and polystyrene with natural fibers such as cellulose and starch (H. C. Obasi & Igwe, 2014). The synthetic polymer and natural biopolymer like starch that have been blended are developed into different properties of plastic materials, and the quantity of starch blend affects its properties.

2.5.1 Mechanical Properties of PP Blend Starch

According to Obasi and Igwe (2014), the increased the starch content, the worst the mechanical and rheological properties of the blend, thus, a compatibilizer is used to improve the properties. The tensile strength decreased by the increasing of starch content due to inadequate stress transfer of poor wetting starch filler by PP matrix (Henry Chinedu Obasi et al., 2015).

According to Oduola and Akpeji (2015) research on effect of starch on propylene properties, the starch content above 30% caused more degradation but reduced the mechanical strength and starch content below 30% improved the mechanical strength but not sufficient for biodegradation. The mechanical properties of polymer will be favourable and degradation can still occur for starch content below 30%. For starch content below 30%, the starch effect positively to mechanical properties like flexural strength and izod impact strength.

2.5.2 Tribology Properties of PP Blend Starch

The surface hardness of the composites affected the tendency of embedded fibers to be ploughed-out during the wear and tear test. Softer surface provides higher adhesion with sliding members, thus, the lower the hardness of the composites, the higher the wear rates (A.A. Latiff et. al, 2015).

Based on research tribology and physical properties on PP filled by natural fibers by Luboš, Petr, Martin, Jiří and Štěpánka (2013), the natural fibers of animals and vegetables give positive influences to the coefficient of friction (COF) of the polypropylene matrix composites. It is said that the friction coefficient decreased when the portion of natural fibers increased.

2.5.2.1 Wear Performance

Wear performance is defined as a tendency of material to lose weight from evacuation and deformation process on the material surface because of mechanical action of the opposite surface because of relative motion (Ã & Partlow, 2004). Specific wear rate (Cowie, Briscoe, Fisher, & Jennings, 2018) can be define as Equation 2.1.

$$W_s = \frac{\Delta V}{F_N D} \tag{2.1}$$

Where W_s = Specific wear rate mm^3/Nm, ΔV = Volume difference, mm^3, F_N = Normal applied load, N and D = Sliding distance, m. The wear performance is said to be greater if the specific wear rate is low (Nirmal, Hashim, & Lau, 2011). However there are a lot of factors affected the wear performances such as the contact condition of sample (i.e. dry or wet condition), the types of reinforcements used (i.e. resin or natural fibers) and also the orientation of sample with respect to the sliding directions.

2.5.2.2 Frictional Performance

Friction performance is the force resisting the relative motion between two sliding boundary. Pin on disc apparatus at certain sliding speed and load applied was employed for abrasive wear test and coefficient of friction (COF) of the polymers composite.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the methodology used in this study to obtain data input for wear and friction properties of polymer composite matrix made by tapioca starch. The flow chart of the experiment is shown in Figure 3.1.

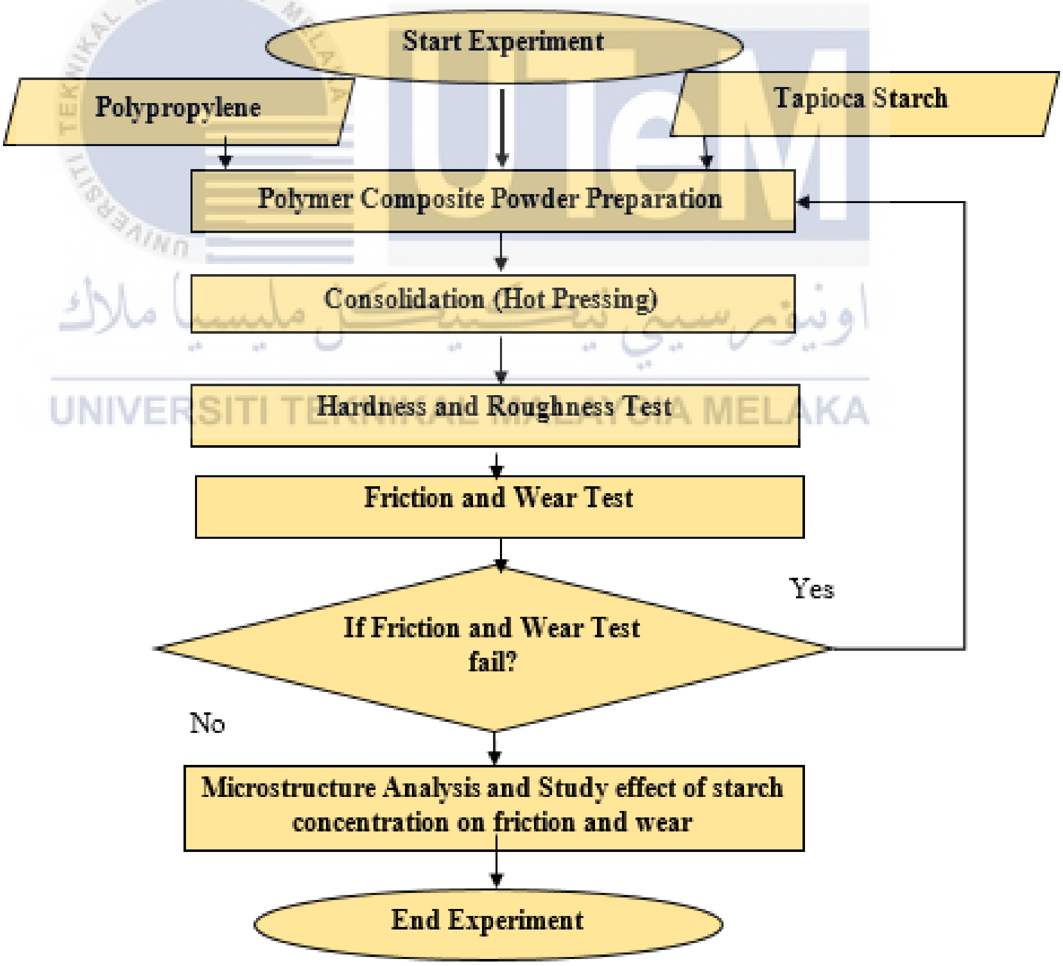

Figure 3.1: Experimental Workflow

The experiment started by obtain the experimental input of the PMC. Polypropylene and tapioca starch were used as the input materials in PMC. The two materials then went for a sample preparation process by mixing them appropriate to the percentage ratio. Then, the consolidation process started by using Hot Press Machine and Shop Press Bearing. The hardness and roughness values were obtained after consolidation process using Durometer and Handheld Profilometer respectively. The friction and wear test then were conducted using Pin-on-disc Tester. If the test fail, then the process undergo the same steps started to prepare a new sample. If succeed, then proceed to Microstructure Analysis and study the effect of starch concentration on friction and wear properties.

3.2 General Experiment Setup

The materials used in the experiment are locally made tapioca starch was bought at a local market (Melaka, Malaysia) and Polypropylene powder. There several processes used during the experiment which are:

3.2.1 Sample Preparation and Milling

The starch was first aired under the sun to remove the presence of moisture in the starch so that the starch not easily gelatinize when heated. Then, the starch and PP were weighted for 12.5g in total. The starch and PP were first weighted separately to their appropriate masses with wt PP/wt starch ratios is 90:10, 80:20, 73:30 and neat PP. The appropriate masses of starch and PP were shown in the Table 3.1.

The starch-PP blend then were mixed in the ball milling for five minutes. Starch was added as fillers to PP to make moulded specimens impermeable to water. Figure 3.2 shows the mould disc-shape.

Table 3.1: Starch/PP Ratio

No.	Starch/PP Ratio	PP Mass (g)	Starch Mass (g)
1	Neat PP	12.500	0.000
2	10:90	11.250	1.250
3	20:80	10.000	2.500
4	30:70	8.750	3.750

Figure 3.2: Mould

3.2.2 Hot Pressing and Cooling Process

A disc mold of diameter 74 mm was used for casting the composite samples. The mold disc was first cleaned using acetone and was applied wax around the surface before put the starch-PP powder. Acetone is a non-polar organic solvent and usually used to dissolve the non-polar organics materials. The mold disc filled with starch-PP powder then was put on the hot press machine. The temperature used for the hot press process was 180°C with pressure 2.5bar for 10 minutes plus 5 minutes to heat the mould. Figure 3.3 shows the Hot Press Machine. The moulded blends (sample) were left in room temperature for cooling process until the temperature of mould decreased to approximately 40°C. Then, the samples were removed from mould using Bearing Shop Press Machine as shows in Figure 3.4.

Figure 3.3: Hot Press Machine

Figure 3.4: Bearing Shop Press Machine

3.2.3 Hardness and Roughness Test

The samples were first measured for their hardness using digital Durometer Shore Hardness Scale shows in Figure 3.5. The values of hardness were then determined by penetration of the Durometer foot into the samples. The hardness reading is changed over varies areas of the samples' surfaces, thus, the reading then were taken three times for each sample to find their average hardness reading. The samples were measured for their roughness using Hand-held Roughness Tester TR200 shows in Figure 3.6. The roughness reading were also taken three times to ensure the data more accurate. All the samples then were drilled with four holes using hand drill machine. The holes size was 4mm appropriate to the pin-on-disc's sample holder.

Figure 3.5: Shore Durometer

Figure 3.6: Hand-held Profilometer

3.2.4 Wear and Friction Test

The dry sliding wear and friction test has been carried out under given condition using pin-on-disc type wear testing machine. Figure 3.7 shows the pin-on-disc tester. The specimens first were weighted before carried out the friction and wear test. Test pieces were cleaned with acetone before and after each test to avoid entrapment of wear debris and to achieve the uniformity in experiments procedure. The samples were then inserted securely and pinned in the sample holder perpendicular (± 1º) to the disc surface when in contact in order to maintain the necessary contact conditions. They were positioned at a particular track diameter where this wear track diameter is to be changed after each test.

Figure 3.7: Pin-on-Disc Tester

The wear track diameter used were 20, 30 and 40 mm respectively. The samples then was abraded for a total sliding distance of 1000 m. The load of 500g was applied through a weight loading system to press the pin against the disc. The 200 rpm of speed of the disc or motor rpm was applied through the controller at the control panel. Table 3.2 below shows the parameters for this experiment that was kept constant for entire experiments. The machine is fixed with data acquisition system where the frictional force that arises at the contact can be read out/recorded directly. The times required for the experiments was calculated using formula time given in Equation (3.1) and (3.2).

$$L = 2\pi rNt \tag{3.1}$$

$$t = \frac{L}{2\pi rN} \tag{3.2}$$

Where, L is the sliding distance in m, r is radius wear track also in m, N is sliding speed in rpm and t is time required in min.

Table 3.2: Tribology Performance Parameters

Parameters	Unit	Value
Sliding Distance	Meter (m)	1000
Sliding Speed	Revolution per minute (rpm)	200
Load	Gram (g)	500
Wear Track Diameter	Millimeter (mm)	20, 30 and 40

Based on Equation (3.2):

For track diameter = 20 mm, the radius track is 10 mm = 0.010 m;

$$t = \frac{1000}{2\pi(0.010)(200)}$$

$$t = 79.577\ min$$

$$t = 1\ hr\ 19\ \text{min}\ 34\ sec$$

For track diameter = 30 mm, the radius track = 15 mm = 0.015 m;

$$t = \frac{1000}{2\pi(0.015)(200)}$$

$$t = 53.052\ min$$

$$t = 53 \text{ min } 3\ sec$$

For track diameter = 40 mm, the radius track = 20 mm = 0.020 m;

$$t = \frac{1000}{2\pi(0.020)(200)}$$

$$t = 39.788\ min$$

$$t = 39 \text{ min } 47\ sec$$

3.2.4.1 Calculation for COF

Friction coefficient was calculated by using COF formula as shown in Equation (3.3) below.

$$COF = \frac{F}{W} \tag{3.3}$$

Where *COF* is coefficient of friction, *F* is friction force in unit newton (N) and *W* is applied load also in unit Newton (N)

3.2.4.2 Calculation for Wear Rate

Wear rate was calculated by measuring the volume loss of the samples where the volume loss was calculated by taking the wear scar radius and wear depth of the samples. The volume loss formula was given Equation (3.4).

$$V_{loss} = 2\pi R \times \pi(a^2 + h^2) \quad (3.4)$$

Where V_{loss} is the volume loss, R is wear track radius, a is wear scar radius and h is a wear depth. All the parameters were calculated in unit 23illimetres (mm) while V_{loss} is in unit mm^3.

The wear depth, h can be calculated by using Equation (3.5)

$$h = r - \sqrt{(r^2 + a^2)} \quad (3.5)$$

Where r is ball bearing radius in unit millimeter (mm). Wear depth and wear track radius can be measured using 3D Non-Contact Profilometer.

The ware rate can be calculated by formula in Equation (3.6).

$$k = \frac{V}{(WxL)} \quad (3.6)$$

Where k is wear rate in mm^3/ Nmm, V is volume loss in mm^3, W is load applied in N and L is sliding distance in mm.

3.2.5 Microstructure Analysis

The morphological test of the sample and wear scar surface were observed and analyse using 3D Non-Contact Profilometer as shown in Figure 3.8.

Figure 3.8: 3D Non-Contact Profilometer

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

Tribology testing was conducted onto the samples according to Chapter 3and the experimental results will be shown in this chapter. The tribology properties of the tapioca starch mixed PP were determined by applying Hardness Test, Roughness Test, Friction Test, Wear Test and Microstructure Analysis.

4.2 Sample

Sample preparation has been done and weighted using appropriate ratio with (0%, 10%, 20% and 30% starch) by consolidation process to form samples with different weight percentages (wt%). The result obtained from the consolidation process gives four samples of polymer composites matrix of polypropylene mix tapioca starch as shows in the Table 4.1.

Table 4.1: Sample of PP Mixed Tapioca Starch

Weight Percentage (wt%)	Specimen
0% Tapioca Starch in PP	

10% tapioca Starch in PP	
20% tapioca Starch in PP	
30% tapioca Starch in PP	

Based on Table 4.1, the specimen with different starch percentage gives the different in colour to the sample formed. Specimen with 0% starch is darker than the specimen with 10% starch. Specimen with 20% starch has light grey colour from the centre while around the fillet is dark grey. 30% starch in PP gives the specimen the colour of light grey. From the sample formed, the higher the starch percentage in PP, the lighter the colour of sample formed. This shows that the starch gives light pigmentation to the sample.

4.3 Hardness and Roughness Testing

The results obtained from hardness and roughness test will be illustrated into graph to understand the effects of increasing filler content of composite toward its hardness and roughness properties.

4.3.1 Hardness Properties

Figure 4.1 shows average value of hardness that are obtained from durometer gauge for each weight percentage of the samples. The hardness test is measured in unit hd. The graph shows the trend of the hardness increase gradually as the weight percentages of the starch filler increases. The hardness recorded for PP is 66.50 hd and the highest is 74.50 hd for weight percentage of starch of 30%. This shows increase of hardness of composite is 9.77% from weight percentage of 0% wt% of starch to 30% starch. This shows that tapioca starch improved the hardness properties of the polymer composite matrix when mixed with PP. Based on Aliyu, Mohammed, and Al-qutub (2018), the nature of the materials that improve strong interfacial bonding between matrix and reinforcement make efficient load transfer mechanism resulted in hardness increment.

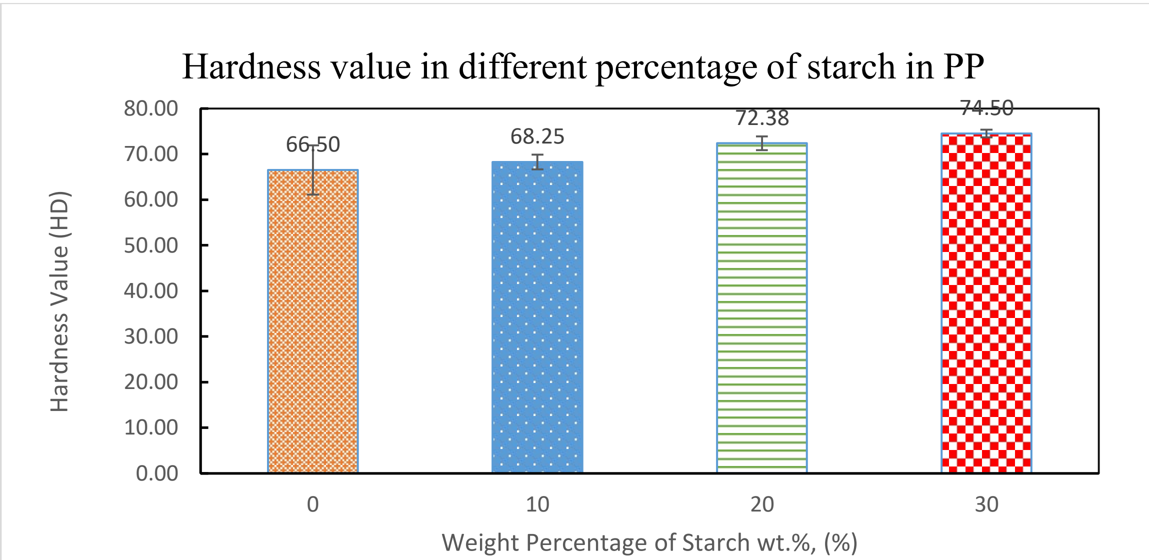

Figure 4.1: Hardness Value of Sample

4.3.2 Surface Roughness

The roughness result obtained for four samples (0%, 10%, 20%, and 30% starch) is shows in Figure 4.2. The roughness test has been done using hand-held profilometer and measured in unit µm. The result shows are the average value calculated by testing three times for each sample. The highest average reading of roughness is 30% starch with 1.3 µm while the lowest is 0% starch with 0.5 µm. The wt10% and wt20% of starch gives the roughness value of 0.7 µm and 0.9 µm respectively. From the graph roughness below, the higher the wt% of starch in PP, the higher the roughness would be. This proven that the starch makes the surface roughness of the polymer composite matrix increased when mixed with PP.

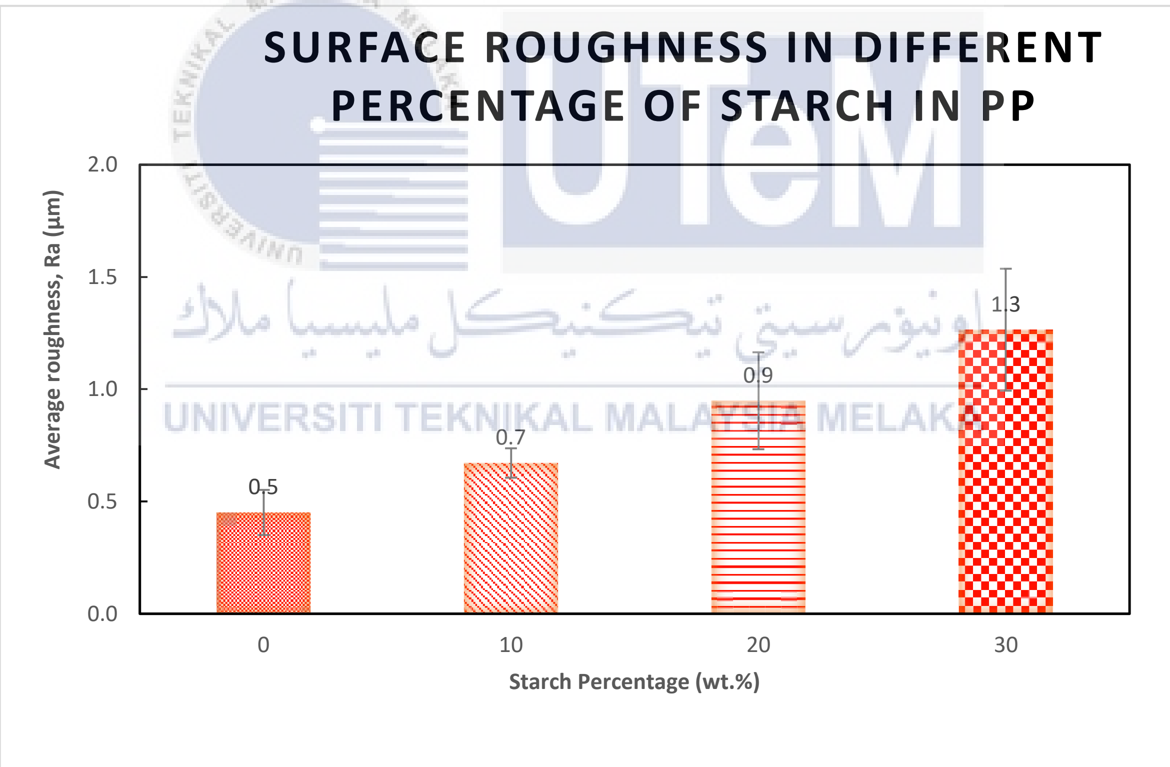

Figure 4.2: Surface Roughness in Different Percentage of Starch in PP

4.4 Tribology Testing

The result of the study of wear and friction of surface polymer composite material for polypropylene and tapioca starch were obtained from pin-on-disc and 3D non-contact profilometer. This results are analysed and illustrated into COF graph and wear rate graph.

4.4.1 Frictional Performance

Generally, friction force is the processes and measures of energy dissipated at the material surface and the behaviour of performance depends on their wt% of fillers. The friction forces were recorded for pure PP and its composites during different sliding conditions of wear track diameter.

The friction coefficient as a function of sliding distance has been shown in Figures 4.3, 4.4, 4.5 and 4.6 for starch wt% of 0%, 10%, 20% and 30% respectively. The average COF reading for wt% of 0% is 0.134 and 0.1067 for COF of wt% 10%. Both wt% of 20% and 30% have COF reading 0.113 and 0.1714 respectively.

Figure 4.7 shows the variation of COF of different percentage of starch in PP under dry conditions. After some initial sliding run, all the composites have gained a steady-state period which were started from sliding distance of 200 m to 400 m. The graph shows that the specimen with 30% starch has the highest average COF reading compared to the others followed by 0%, 10% and 20%.

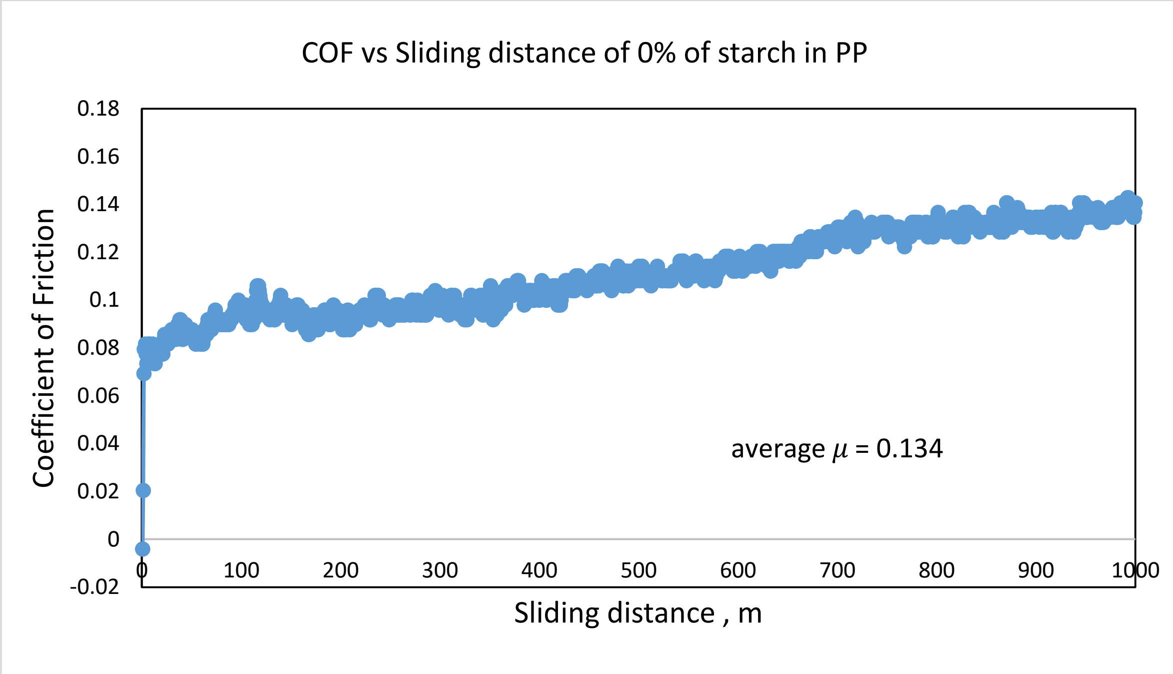

Figure 4.3: The Effect of 0% Tapioca Starch on COF of PP Composite Against Stainless Steel Ball

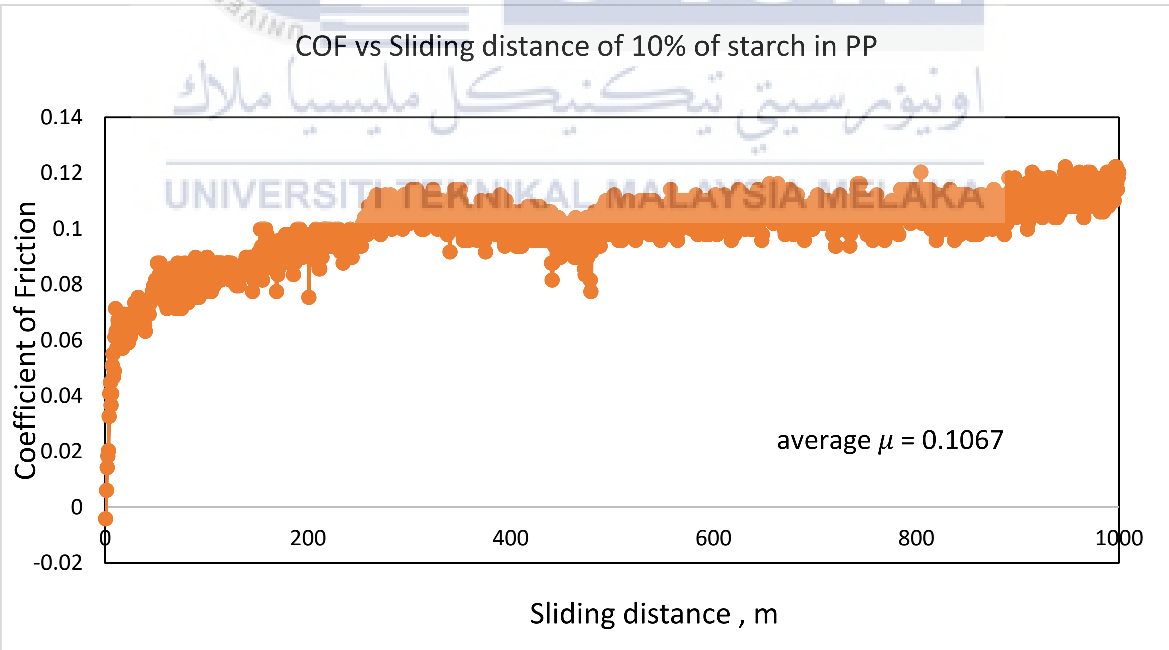

Figure 4.4: The Effect of 10% Tapioca Starch on COF of PP Composite Against Stainless Steel Ball

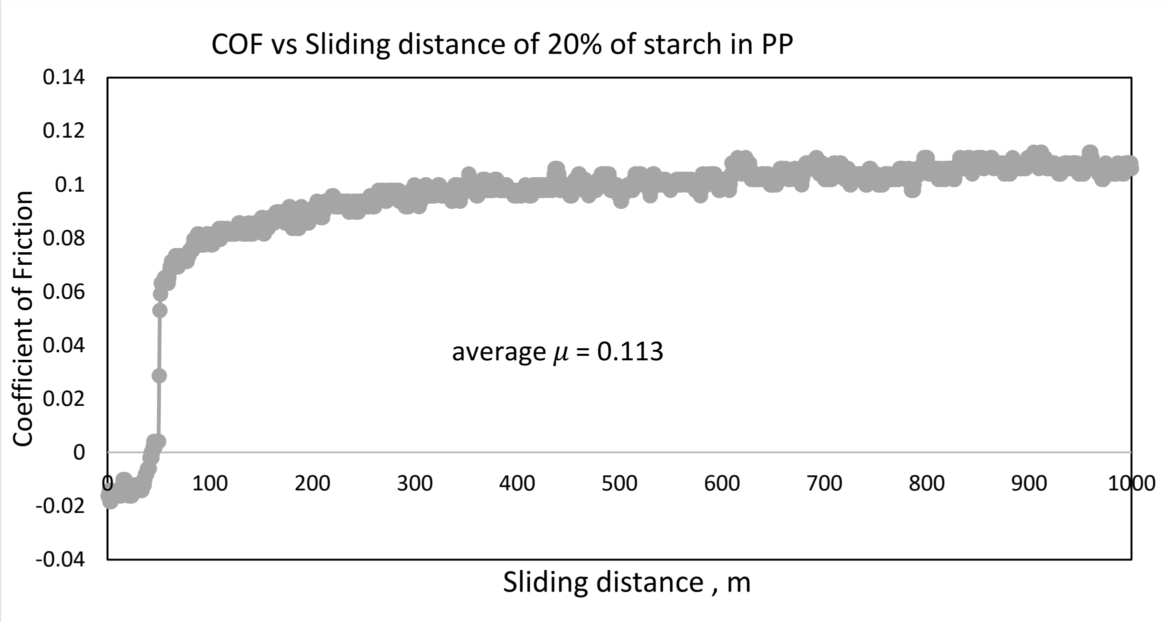

Figure 4.5: The Effect of 20% Tapioca Starch on COF of PP Composite Against Stainless Steel Ball

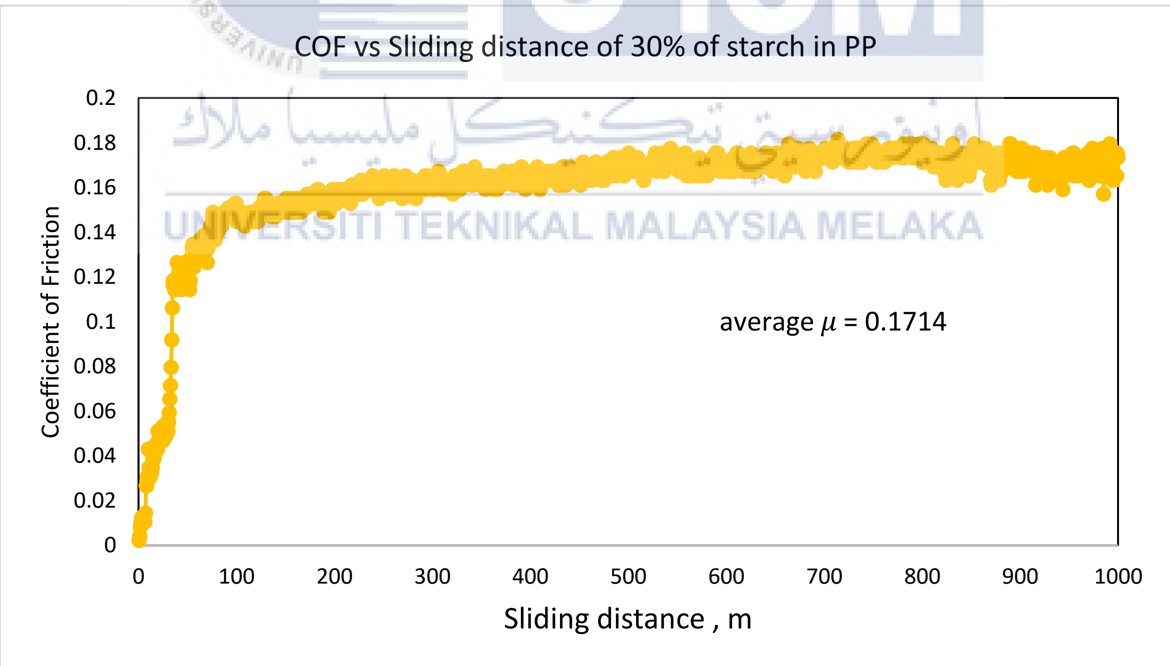

Figure 4.6: The Effect of 30% Tapioca Starch on COF of PP Composite Against Stainless Steel Ball

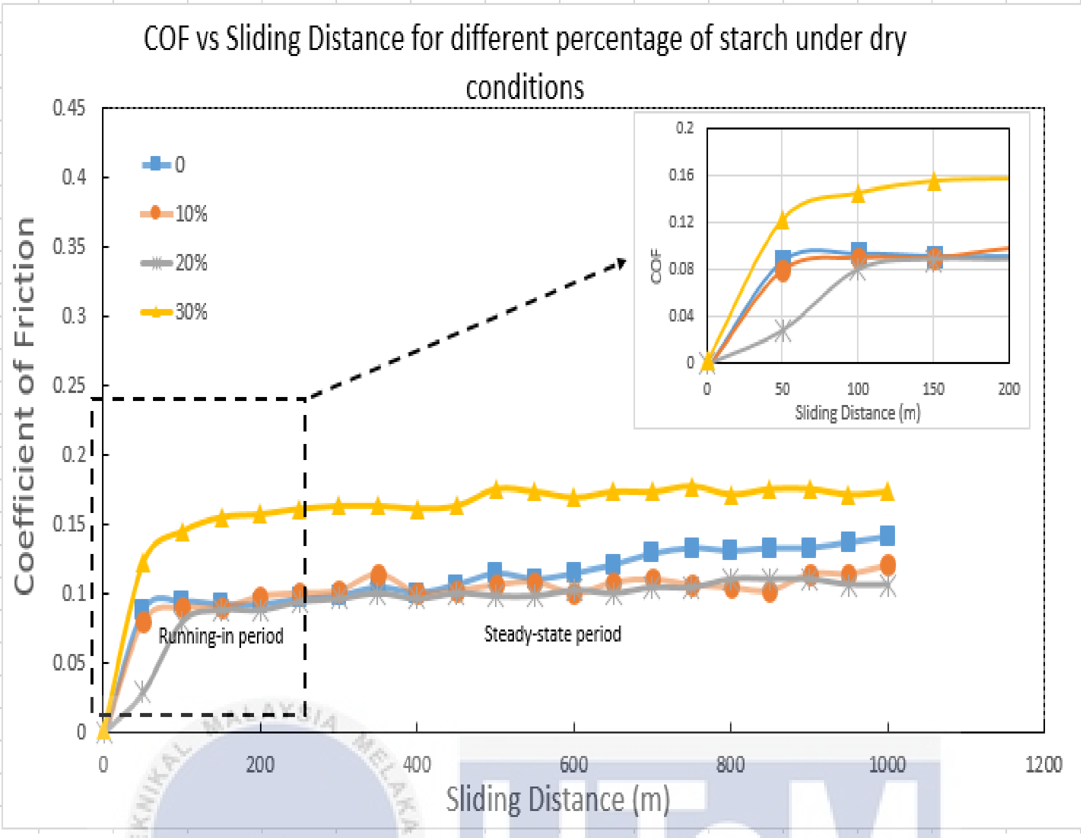

Figure 4.7: Variation of COF of The Composite with Different wt% of Tapioca Starch in PP

Figure 4.8 shows the graph of average COF at steady-state period vs starch percentage in PP to shows the effect of different percentage of starch in PP on COF under dry condition. From wt% of 0% to 20%, the average steady state of COF is decreased gradually by 20.67%. The COF reading then suddenly increased by 26.09% during the starch wt% of 30%. Under dry condition between counterface and various starch percentage of specimen, as the wt% increase the contact surface of rubbing part increases. The transfer film that contains starch particles acted as lubricant layer which in turn reduces and hamper the direct contact between the PP and the hard counterface caused the reason of the low friction of polymers filled with tapioca starch.

According to Shalwan & Yousif (2012), the presence of natural fibres on the composite surface smoothen the film transfer on the counterface, which led to decrease the interlock between the asperities in contact leading to low friction coefficient. However, in this case, the friction coefficient is still high for wt% of 30% to be used in tribological applications such as bearing, sliding and bushes. To be observed that the sudden increased in 30% starch shows that the optimum of starch resulted in minimum cof is 20% of starch concentration. The further increment of tapioca starch concentration will increase the cof value.

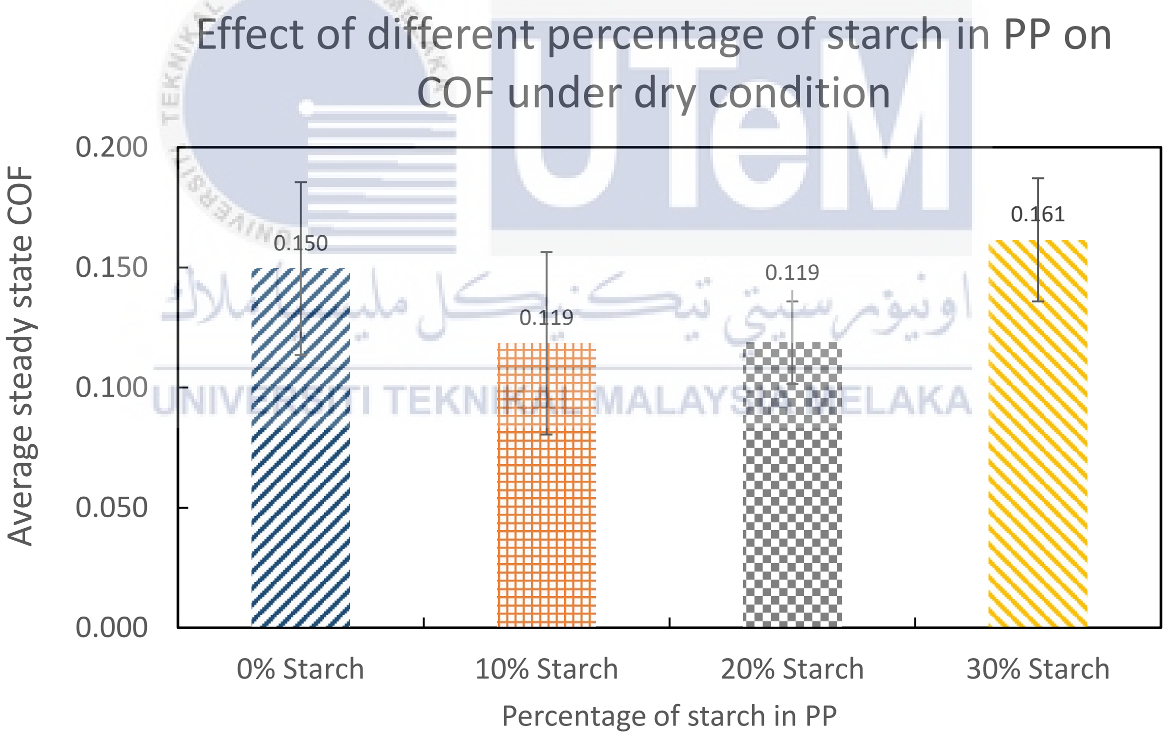

Figure 4.8: Effect of Different Percentage of Starch in PP on COF under Dry Condition

4.4.2 Wear Rate Performance

The specific wear rate is obtained by using the equation mentioned in Chapter 3 and the data measured is illustrated in the graph. From the equation 3.4 and 3.6, the volume loss and wear rate are calculated. For specimen of pure PP, the wear rate is:

$$V_{loss} = 2\pi(15) \times \pi(0.2239^2 + 0.0036^2)$$

$$V_{loss} = 14.847\ mm^3$$

$$k = \frac{14.847}{(4.905)(1x10^6)}$$

$$k = 3.027x10^{-6}\ mm^3/Nmm$$

For specimen of 10% wt of starch, the wear rate is:

$$V_{loss} = 2\pi(15) \times \pi(0.2184^2 + 0.0040^2)$$

$$V_{loss} = 14.128\ mm^3$$

$$k = \frac{14.128}{(4.905)(1x10^6)}$$

$$k = 2.880x10^{-6}\ mm^3/Nmm$$

For specimen of 20% wt of starch, the wear rate is:

$$V_{loss} = 2\pi(15) \times \pi(0.2108^2 + 0.0073^2)$$

$$V_{loss} = 13.173\ mm^3$$

$$k = \frac{13.173}{(4.905)(1x10^6)}$$

$$k = 2.686x10^{-6}\ mm^3/Nmm$$

For specimen of 30% wt of starch, the wear rate is:

$$V_{loss} = 2\pi(15) \times \pi(0.2074^2 + 0.0043^2)$$

$$V_{loss} = 12.742\ mm^3$$

$$k = \frac{12.742}{(4.905)(1x10^6)}$$

$$k = 2.598x10^{-6}\ mm^3/Nmm$$

From the wear rate calculation, the graph of wear rate vs starch percentage is presented as shown in Figure 4.9. This graph shows the effect of different percentage of starch in PP on wear rate under dry condition. The graph shows that the wear rate is decreased gradually with the increasing of starch percentage in PP. Sample with 0% starch percentage has the highest wear rate which is $3.027x10^{-6}$ mm^3/Nmm. Followed by wear rate of sample with 10% starch which is $2.88x10^{-6}$ mm^3/Nmm. The wear rate for 20% and 30% of starch are $2.686x10^{-6}$ mm^3/Nmm and $2.598x10^{-6}$ mm^3/Nmm respectively. The wear rate decreased by 14.17% from wt 0% starch to wt 30% starch in PP.

This graph explained that the starch had effected and reduced wear rate in polymer composite of tapioca starch mixed PP. The result shows that wear performance of pure PP has improved after combination of natural fibres as the wear rates of the develop composite was lower than the wear rate of neat PP similar to the result trend obtained by (Bajpai, Singh, & Madaan, 2012). The wear rate result may be due to the fact that the PP during sliding would softens due to rise in temperature and is separated as a film.

The reinforcement of different percentage of starch caused the different in behaviour of the samples with same sliding parameters. This observation shows that the sliding wear characteristic depends upon the wt% of tapioca starch and the interaction with PP. Samples with wt% of 30% showed poor bonding between fibre and matrix caused it to have lowest wear rate. According to (Bajpai et al., 2012), after sliding experimentation, due to plastic deformation, patches of thin polymer film were created over the fibres cross section which protect the composite surface and contribute to good wear resistance. This shows that there is good interfacial characteristic between fibres and polymers.

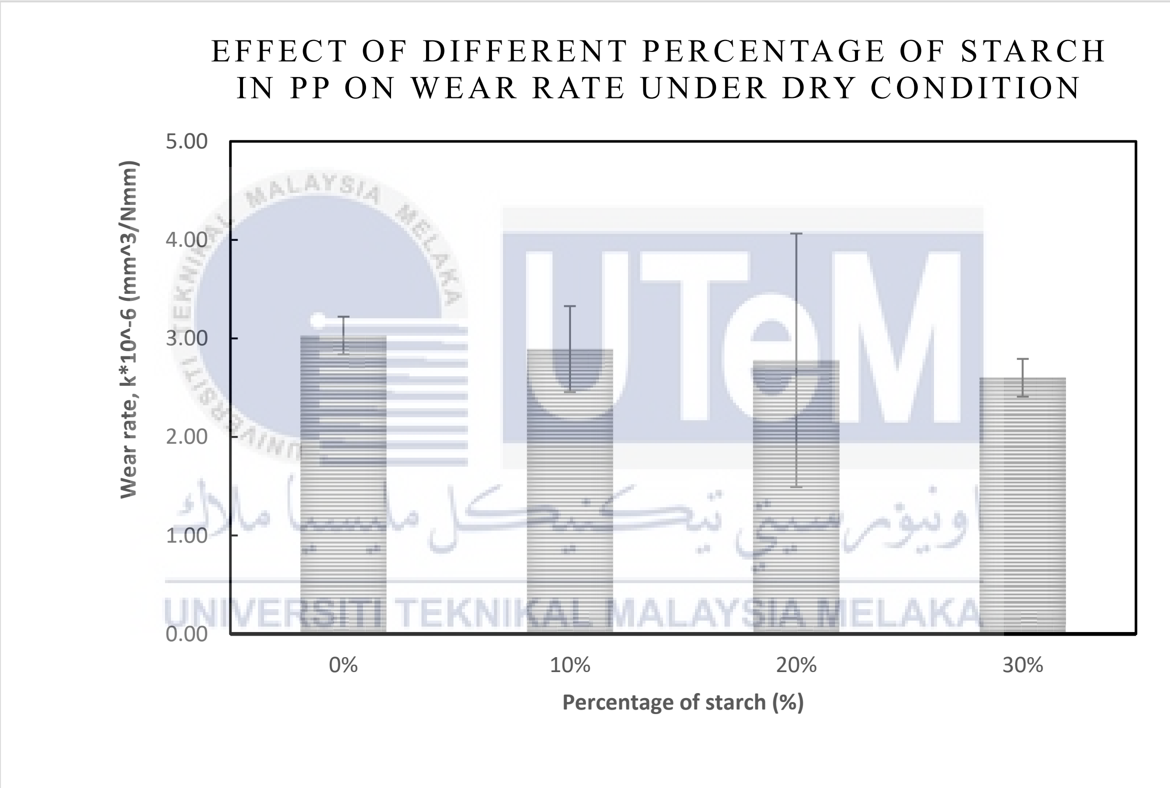

Figure 4.9: Effect of Different Percentage of Starch in PP on Wear Rate under Dry Condition

4.5 Microstructure Analysis

The microscopic observation of worn specimen of the PMC at different starch percentage are shown in Figure 4.10. The neat PP shows more wear scar and obviously seen through the microscopic observation compared to the other samples. Whereas the sample with 30% starch shows that the wear scar hardly to detect in microscopic analysis. Through this microscopic observation, the wear scar on the samples represent that the starch have improved the wear rate performance of the PMC by reducing its specific wear rate and wear scar.

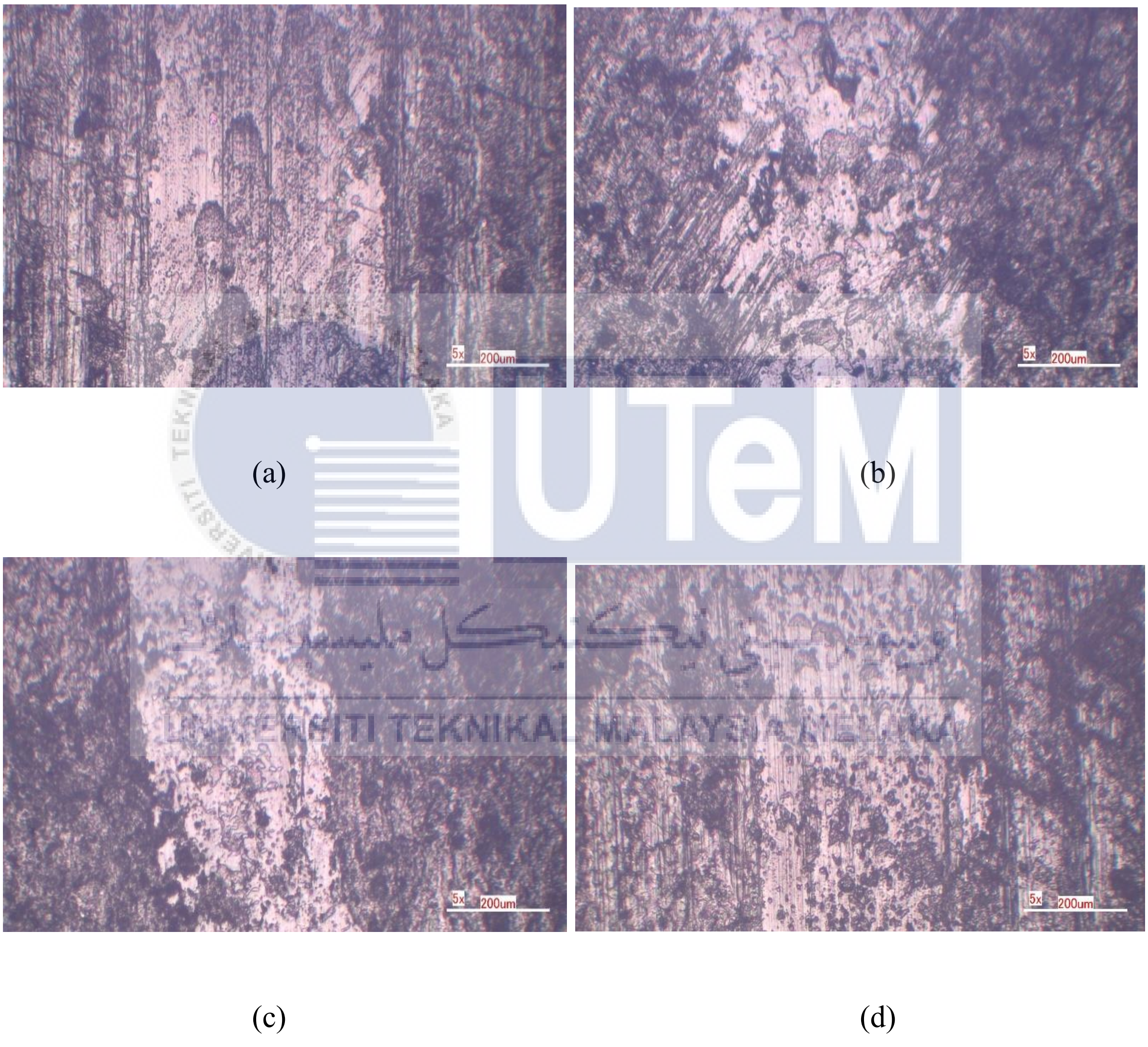

Figure 4.10: Surface Morphology of the PMC Made by Tapioca Starch at Weight Percentage wt% at (a) 0 (b) 10 (c) 20 (d) 30

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

As a summary, the PMC of PP mixed with tapioca starch were developed with the main objective to gain a materials with improved properties and materials. The sample was fabricated using hot press machine with four different filler wt% content which is 0%, 10%, 20% and 30%. Those fabricated composite samples have undergo hardness test, roughness test, wear test, friction force test and microstructure analysis in order to achieve the objectives of the study.

Results obtained from the test shows that the addition of tapioca starch have improved the mechanical properties of the PMC. It increased the hardness and roughness of the composites by increasing the wt% of starch in PP. The combination of tapioca starch also decreased the COF and wear rate of the composite. The average COF of the composite has decreased when the wt% increased by 20.67% and suddenly decreased at 26.09% during the wt% of 30% under similar sliding conditions. Wear performance of PP was significantly improved due to incorporation of tapioca starch as the specific wear rate of developed composites was lower than the specific wear rate of the PP. Based on result obtained in Chapter 4, the specific wear rate is decreased when the starch wt% increased. It is decreased by 14.17% from neat PP to wt% of 30%. This shows that good interfacial characteristics between fibres (tapioca starch) and polymers (PP). From the result obtained, wear rate decreased to the hardness increased which is similar to (A.A. Latiff et. al, 2015) where the lower the hardness of composite, the higher the wear rate. This is due to the softer surface provide higher adhesion with sliding members. The difference in behaviour of COF and wear rate of different sample is due to the bonding level of the different wt.% of sample with PP matrix. The worn surface morphology of the samples showed that the wear scar reduce when the starch percentage increased, thus, result in good wear performance of the composite.

Thus, it can be concluded from the results that higher percentage of starch in PP has stronger effect on hardness performance, COF performance and wear performance compared to the neat PP. The objective of this study is achieved.

5.2 Future Work Recommendation

There is a great potential in PMC made by tapioca starch which can be furthered explored besides mechanical and tribology properties, which are chemical and thermal properties. These properties also play a role in order to determine the correlation and bonding between the fibres and the polymers in wear rate and COF performance. The same goes to the mechanical properties. It can be further explored in other properties include tensile stress, yield stress, yield strain, tensile strain and so on. These properties gives better explanation to the tribology performance of the PMC.

Next is the wear rate and COF performance also can be furthered investigated in other sliding parameters such as sliding under wet condition, under different loads and different sliding speed. From the previous researches on PMCs, these sliding conditions gives different performance on wear and friction.

Lastly is SEM Analysis is needed to study and investigate in detail the interaction of the bonding of the film specimen of composite.

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APPENDICES

A1: Gantt Chart for PSM1

No.	Task	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16
1.	Project Title Selection																
2.	Literature review from previous research subjected on the title																
3.	Design experiment and express using process flow chart																
4.	Mini presentation on the progress of PSM																
5.	Sample preparation using Hot Press Machine, Ball Milling and Bearing Shop Machine																
6.	Testing on hardness, roughness and friction force using pin-on-disc																
7.	Submission of progress report																
8.	Submission of final report 1																
9.	PSM1 seminar																

A2: Gantt Chart in PSM 2

No.	Task	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16
1.	Discussion on previous report on PSM1 and correction																
2.	Continue the friction force from PSM1 using pin on disc																
3.	Report PSM 2 progress and submission																
4.	Wear testing and microstructure analysis using 3D non-contact profilometer																
5.	Prepare on Chapter 4																
6.	Do research on previous research on the discussion of the results																
7.	Prepare on conclusion and future recommendation																
8.	Compile PSM2 & submission																
9.	PSM2 seminar																