DEVELOPMENT OF BIO-LUBRICANT FROM WASTE MUSA PARADISIACA ENHANCE BY CRYSTALLISED STRUCTURE OF SCALLOP-SHELL NANOPARTICLES

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BACHELOR OF MECHANICAL ENGINEERING TECHNOLOGY (MAINTENANCE TECHNOLOGY) WITH HONOURS

2023

Faculty of Mechanical Technology & Engineering

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**A thesis submitted
in fulfilment of the requirements for the degree of
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BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA

TAJUK: **DEVELOPMENT OF BIO-LUBRICANT FROM WASTE MUSA PARADISIACA ENHANCE BY CRYSTALISED STRUCTURE OF SCALLOP-SHELL NANOPARTICLES**

SESI PENGAJIAN: **2023-2024 Semester 1**

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I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering Technology (Maintenance Technology) with Honours

Signature	:	
Supervisor Name	:	Dr. Muhammad Ilman Hakimi Chua Bin Abdullah
Date	:	12 JAN 2024

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DEDICATION

I dedicate this works to my beloved parents and my supervisor Dr. Muhammad Ilman Hakimi Chua Bin Abdullah, who offered unconditional love and support and have always been there for me. Thank you so much for giving me strength to finish my Final Year Project.

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ABSTRACT

Nowadays, lubrication oil is widely used in various fields. Traditional lubrication oils sourced from petroleum oil cause serious pollution to the environment especially to soil and water resources when they enter through various channels such as transportation, leakage, splashing, spillage, or improper discharge. The study on the countermeasure of these issues leads to the development of lubricant from organic sources which tend to get attention these days. Extraction oil from vegetable or fruit waste offers high promise as a petroleum-based replacement. This study aims to formulate a new bio-based oil from the banana peel with the addition of scallop-shell nanoparticles as additives. The process involves extracting the banana peel oil by using Soxhlet Extraction Fat Analyzer SZF-06A machine, the extracted oil was mixed with 0.5 vol% of Scallop-Shell nanoparticles as an additive, and the samples were then homogenised by ultrasonication. A tribological test was conducted by using a four-ball tester according to the ASTM D-4172 where the CoF and WSD were evaluated for each sample. SEM was conducted to verify the wear mechanism occur. Samples with Scallop-Shell nanoparticles were shown to have the best CoF (0.08385) and WSD (0.67mm) results in developing a new bio- lubricant. As a result, scallop-shell nanoparticles improved their physical properties, along with enhancing the good anti-wear and anti-friction characteristics of the lubricant mixtures compared to mineral oil. Banana peel oil have met the essential criteria as a bio-based lubricant and can replace mineral oil derived from petroleum oil as a new, advanced, renewable bio-based lubricant for industrial applications that care for the environment and save costs.

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ABSTRAK

Pada masa kini, minyak pelincir digunakan secara meluas dalam pelbagai bidang. Minyak pelincir tradisional yang diperoleh daripada minyak petroleum menyebabkan pencemaran yang serius kepada alam sekitar terutamanya kepada tanah dan sumber air apabila ia masuk melalui pelbagai saluran seperti pengangkutan, kebocoran, percikan, tumpahan, atau pelepasan yang tidak betul. Kajian mengenai tindakan balas terhadap isu-isu ini membawa kepada pembangunan pelincir daripada sumber organik yang cenderung mendapat perhatian hari ini. Minyak perahan daripada sisa sayuran atau buah-buahan menawarkan janji yang tinggi sebagai pengganti berasaskan petroleum. Kajian ini bertujuan untuk merumuskan minyak berasaskan bio baharu daripada kulit pisang dengan penambahan nanopartikel kulit kerang sebagai bahan tambahan. Proses ini melibatkan pengekstrakan minyak kulit pisang dengan menggunakan mesin Soxhlet Extraction Fat Analyzer SZF-06A, minyak yang diekstrak dicampur dengan 0.5 vol% nanopartikel Kerang-Shell sebagai bahan tambahan, dan sampel kemudiannya dihomogenkan dengan ultrasonik. Ujian tribologi telah dijalankan dengan menggunakan penguji empat bola mengikut ASTM D-4172 di mana CoF dan WSD dinilai untuk setiap sampel. SEM telah dijalankan untuk mengesahkan mekanisme haus berlaku. Sampel dengan nanopartikel Scallop-Shell telah ditunjukkan mempunyai CoF (0.08385) dan WSD (0.67mm) terbaik yang menghasilkan pelincir bio baharu. Hasilnya, nanopartikel kulit kerang menambah baik sifat fizikalnya, bersama-sama dengan meningkatkan ciri anti haus dan anti geseran yang baik bagi campuran pelincir berbanding minyak mineral. Minyak kulit pisang telah memenuhi kriteria penting sebagai pelincir berasaskan bio dan boleh menggantikan minyak mineral yang diperoleh daripada minyak petroleum sebagai pelincir berasaskan bio baharu yang termaju dan boleh diperbaharui untuk aplikasi industri yang menjaga alam sekitar dan menjimatkan kos.

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LIST OF ABBBREVIATIONS

ASTM	-	American Society for Testing and Material
CoF	-	Coefficient of Friction
SEM	-	Scanning Electron Microscope
TEM	-	Transmission Electron Microscope
WSD	-	Wear Scar Diameter

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CHAPTER 1

INTRODUCTION

1.1 Background

The use of fruit oils as a bio-lubricant has a long history dating back to ancient times, with sesame and olive oils being used as lubricants in India and Rome respectively. Vegetable oils were used as lubricants in the early 1900s, but their use was limited due to poor performance and stability at high temperatures. However, with the growing demand for sustainable alternatives, there has been renewed interest in vegetable oils as bio-lubricants, with research focusing on the use of fruit oils such as palm, coconut, and castor oils. Today, fruit oil is widely used in the production of biological lubricants due to its high viscosity index, good lubricity, and high oxidation stability.

Fruit oil is oil that is extracted from the fleshy part of a fruit. Fruits such as palm, coconut, olive, avocado, and others are common sources of fruit oils. These oils are extracted from the fruit using various methods, such as cold-pressing or solvent extraction. Fruit oils are used in a wide range of applications, including cooking, skincare, and cosmetic products, and have also gained attention as a potential raw material for bio-lubricants due to their renewable nature, biodegradability, and low toxicity. Different types of fruit oils have different uses and properties such as high viscosity index, oxidative stability, and good low-temperature performance. The advantages of using fruit oil are lower carbon footprint, reduced air pollution, and biodegradability.

Banana oil, also known as isoamyl acetate, is a natural, renewable compound that has shown promise as a potential bio-lubricant. As an ester, banana oil has desirable lubricating properties such as low viscosity, high flash point and good thermal stability. Plus, it's biodegradable and non-toxic, making it an environmentally friendly alternative to traditional petroleum-based lubricants. In recent years, there has been growing interest in exploring the potential of banana oil as a bio-lubricant in a variety of applications, including industrial machinery and automotive engines. As research continues on the use of banana oil as a bio-lubricant, it may offer a promising solution to reduce the environmental impact of lubricants while providing effective lubrication.

In recent years, bio-lubricants have attracted much attention due to their environmental friendliness and ability to provide better lubricating properties than conventional lubricants. Bio-lubricants are derived from natural sources such as fruit oils, vegetable oils and other renewable sources. In this report, we focus on the development of bio-lubricants from discarded banana peel and enhance their performance through the crystalline structure of scallop-shell nanoparticles. Sonication is the process of applying sound energy to agitate and mix particles or broken fibers in a liquid. This wave usually uses a frequency equal to or higher than 20 kHz and belongs to the range of ultrasound, so the process is also called ultrasonication. (Chew & Ali, 2021). During sonication, ultrasonic waves travel through a series of compressions. Because of the high-frequency fluctuations, ultrasonic waves produce mechanical vibrations that create stable foam and eddies in the liquid. These foams and eddies can strip the nanoparticles outside the carbon nanotubes by diffusion and disintegration. As a result, individual nanoparticles are separated and high-quality dispersion can be achieved (Gou et al., 2012).

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1.2 Problem Statement

Lubricating oil is widely used in aviation, automobile, mechanical processing, transportation, metallurgy, coal, construction, light industry, and other industries. Traditional lubricating oil base oils are made of materials with good chemical stability, wide sources, and cheap prices, such as petroleum products. Lubrication needs to play a huge role, but because traditional lubricating oil will inevitably enter the environment through various channels such as transportation, leakage, splashing, spillage, or improper discharge, it will seriously pollute soil and water resources, and destroy the ecological environment and ecological balance. Therefore, there is a need to find lubricants that can be made from renewable energy sources.

It is expected that 50% of all lubricants used globally end up in the environment without proper disposal procedures. Biodegradable oils are generally less flammable and less injurious to plants or animals. Biodegradable lubricants such as synthetic or vegetable oils are more environmentally friendly and less toxic to plants and animals. More biodegradable lubricants are being developed for different specifications, such as hydraulic oils, which are more biodegradable and less toxic to operate in more environmentally sensitive areas. One of the main concerns with petroleum-based lubricant oil is its potential to release harmful volatile organic compounds (VOCs) into the air. When these oils are exposed to high temperatures or when they are burned, they can release VOCs such as benzene, toluene, and xylene, which can be harmful when inhaled.

According to Globe Newswire, the global bio-based lubricants market size collected USD 2.8 Billion in 2022 and is set to achieve a market size of USD 4.9 Billion in 2032 growing at a CAGR of 5.2% from 2023 to 2032. The global bio-based lubricants market is expected to grow significantly due to the rising demand for eco-friendly lubricants in various industries such as automotive, construction, and marine. While bio-based lubricants have many benefits, they may not always perform as well as traditional lubricants in certain applications. This can be a barrier to adoption, particularly in high-performance industries such as aerospace and automotive.

1.3 Objectives

The objectives of this project are stated below;

1. To extract the banana peel as a new bio-based oil.
2. To formulate new bio-based oil from the banana peel with the addition of scallop-shell nanoparticles as additives.
3. To test and analyse the tribological behaviour of the new bio-based lubricant.

1.4 Scope of Research

The scopes of this research are as follows:

1. Extracting the banana peel for developing new bio-based oil.
2. Formulating pure bio-based oil accordingly to ASTM by addition of scallop-shell nanoparticles.
3. Testing the develop bio-based oil according to ASTM D4172.
4. Analysing the surface for developing bio-based oil.

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CHAPTER 2

LITERATURE REVIEW

2.1 Waste Musa Paradisiaca

According to Wikipedia, the cross between Musa Acuminata and Musa Balbisiana has an accepted name called Musa paradisiaca. Most cultural bananas and plantains are triploid cultivars either of this cross or of Musa Acuminata only. Linnaeus at first just applied the name Musa Paradisiaca for plantains or culinary bananas, but modern uses include hybrids of culinary and dessert bananas. Linnaeus named the dessert banana as Musa Sapientum, thus which is a synonym for Musa paradisiaca ("Musa × paradisiaca", 2023). Banana belongs to Musa paradisiaca of the family Musaceae and is a central fruit crop of the tropical and subtropical regions of the world grown on about 8.8 million hectares. Usually, people eat banana fruit and throw away the banana peel. Thus, banana peel is one of the waste products called waste Musa paradisiaca.

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2.1.1 Description of the banana plant and its parts

The banana plant (Figure 2.1) is the largest herbaceous flowering plant. All of the above-ground parts of a banana plant grow from a structure commonly known as a "corm". The plants are usually tall, sturdy, and have a tree-like appearance, but what looks like a trunkis in fact a "false stem" or pseudo stem. Bananas can grow in a variant of soils, as long as the soil is at least 60 cm (2.0 ft) deep, well-drained, and not compacted. Banana plants are among the most rapidly mature of all plants, with a surface growth rate of 1.4 square meters (15 square feet) to 1.6 square meters (17 square feet) per day.

Figure 2.1: Banana Tree

The compositions of banana leaves Figure 2.2 are stem (petiole) and vane (lamina). The petiole base broadens to become a sheath, the sheath which is tightly wrapped constitutes the pseudo stem, and the pseudo stem is all that sustains the banana tree. The sheath edges meet when first produced, giving it a tubular shape. The edges are forced separate as fresh growth takes place in the centre of the pseudo stem. The characteristic of banana leaves are watertight, big, and elastic. In South Asia and some Southeast Asian nations, banana leaves are frequently used as an eco-friendly one-use food container or "dish".

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Figure 2.2: Banana Leaves

Banana fruits (Figure 2.3) develop from the banana heart, in a large hanging cluster, made up of tiers (called "hands"), with up to 20 fruits in a tier. The fruit of this plant is leathery in nature and is called a banana. It has an outer protective layer called the fruit peel or skin. The pericarp contains many slender, string-like structures known as phloem bundles. Phloem bundles extend longitudinally and are present between the pericarp and the edible part.

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Figure 2.3: Banana

The edible part of the fruit can be divided longitudinally into three parts. These three parts correspond to the three carpels. The edible part of a banana can be split into three different parts, the epicarp, mesocarp and endocarp as shown in Figure 2.4. The epicarp is the outermost part of the fruit. It is often referred to as the skin or covering of the fruit. The next part is the mesocarp which is the middle part of the banana fruit. The mesocarp extends to the innermost part of the fruit and is known as the endocarp. The endocarp is the part that gets eaten. The endocarp is the inner part of the fruit, which contains the seeds. These seeds sometimes turn into tiny black spots.

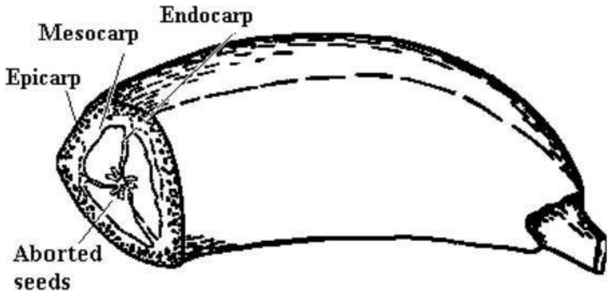

Figure 2.4: Layer of Banana

Ripe bananas taste sweeter than less ripe bananas because of their high sugar content, while less ripe banana contains more starch. This is because the gas ethylene will be produced by banana during ripening. Gas ethylene produced by banana will stimulate amylase to form, amylase is an enzyme that decomposes starch to become sugars, which affects the banana's taste.

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2.1.2 Uses of waste Musa Paradisiaca

The outer shell (cover) of the banana fruit is known as banana peel. After eating the banana fruit, people usually will throw away the banana peel. Thus, banana peel is the waste Musa paradisiaca. However, there are a lot of uses for banana peel such as making banana peel oil for hair and skin care, purifying water, used as an ingredient in cooking, used as feed for livestock, fertilising plants, making many biochemical products like base oil for bio-lubricant, etc. (Hikal et al., 2022).

2.1.3 Potential for oil extraction

For making bio-lubricant base oil, middle part of the banana fruit or the inner part of the banana peel called mesocarp will be used because this part has a composition called follicular gel. Follicular gel provides lubricating properties to the banana peel. That's why people fall when they step on a banana peel. The composition of follicular gel is polysaccharides and proteins (Gupta et al., 2019). When the banana peel is compressed during sliding, the cellulose membrane of the follicle is crushed, then the follicle gel will be released and formed a homogeneous solution. The solution forms a lubricating fluid film between the shoe and the surface that decreases friction. According to the University of Science and Technology in Hong Kong by Jason Long Him Cheung, the coefficient of friction (CoF) for banana peel when stepped by shoe on the surface is about 0.066, which is lower than that of a well-lubricated surface (0.1). A lower CoF means a smoother surface. Therefore, this property holds great potential for new types of lubricant development.

On the contrary, the reason of using oil extracted from waste banana peels or known as bio-lubricant is because synthetic oils, although cheap and easy to produce in large quantities, pollute the environment by producing a lot of chemicals, waste, and carbon emissions. Besides, using waste banana peels to make oil can also greatly reduce waste products on the earth. It can play a role in environmental protection and caring for the environment. Moreover, it has excellent lubricity, less toxic to environment, high viscosity index, renewable and eco-friendly, spill remediation and safer.

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2.2 Lubrications

According to Wikipedia, lubrication is the process of using lubricating oil to reduce friction and wear between two contacting surfaces. The study of lubrication is a subject of tribological understanding. Lubrication mechanisms such as fluid lubrication systems are designed so that the applied load is partially or fully carried by hydrodynamic or hydrostatic pressure, thereby reducing friction and wear between solids. Depending on the degree of surface separation, different types of lubrication can be distinguished. Lubricating oils are usually made up of two main elements, base oil (70%-90%) and additives that change or improve the properties of the base oil (Armylisas et al., 2018). Base oil mainly comes from resources that are not able to be renewed, such as mineral oil, which can be divided into mineral oil and synthetic oil.

Adequate lubrication keeps machine components running smoothly and continuously, reduces wear rates, and prevents bearing overload or seizure. When lubrication fails, components scrub against each other destructively, causing heating, localized welding, destructive damage, and failure.

2.2.1 Type of Lubricant

A lubricant, sometimes called "lube", is a substance (usually a liquid) used between two moving surfaces to reduce friction between them, thereby increasing efficiency and reducing wear. Lubricants are specifically designed to lower the rub and wear of contacting surfaces of two machine parts. In 1999, approximately 37.3 million tons of lubricants were depleted worldwide. Automotive applications including electric vehicles dominate, but other industries such as marine and metalworking also consume large amounts of lubricants. Even though gas lubricants are well known, liquid lubricants dominate the market, followed by solid lubricants.

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Lubricant viscosity is the most important property of fluid lubricants. This is because it determines the friction between sliding surfaces and whether a sufficiently thick film can be formed to avoid wear from contact between solids. The viscometer can measure the viscosity by measuring the flow of lubricating oil under standard conditions, the greater the flow, the lower the viscosity. In most liquids, viscosity decreases significantly with increasing temperature. Fluids are often rated according to the viscosity index because it is desirable to maintain friction-reducing properties with small fluctuations in viscosity under changes in temperature. The higher the viscosity index, the smaller the change in viscosity with temperature.

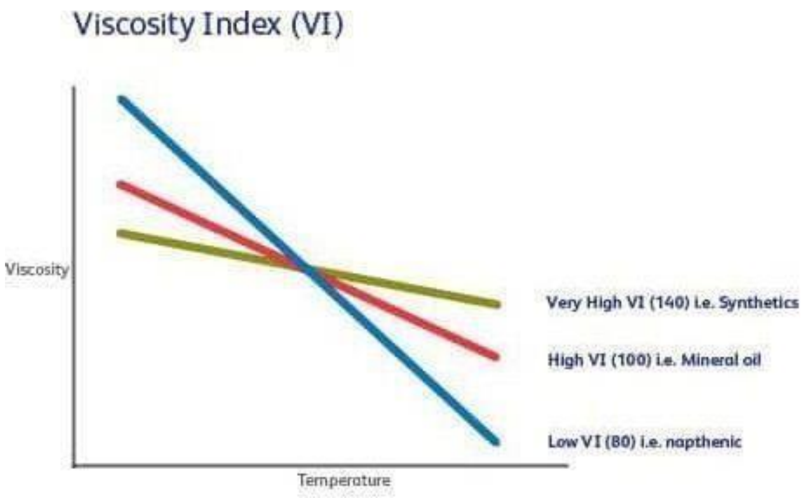

Figure 2.5: Viscosity Index Diagram

The function of a lubrication oil is generally a substance that reduces friction between contacting parts. Depending on the type, lubricants perform other functions such as reducing oxidation, thermal regulation, sealing against dust or dirt, power transmission, and preventing corrosion. Liquid form lubrication is indispensable for long life of high-speed bearing. It is very useful in common machinery, while semi-solid form lubrication such as greases are adequate in low-speed mechanisms. Lubricants are usually liquid or semi-solid form, but they may also exist in different forms. The types of lubricant and its examples are shown in Table 2.1.

Table 2.1: Lubricant types and example

Types of Lubricant	*Examples*
Solid	Graphite, Polytetrafluoroethylene, Molybdenum disulphide
Semi-Solid	Grease
Liquid	Water, natural or synthetic oils
Gaseous	Air

For lubrication oils selection, load and speed are two major factors. We need to consider the speed and load to choose the most suitable lubricant. The selection method of lubricating oil is shown in Figure 2.6.

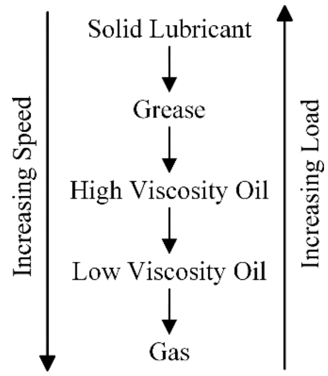

Figure 2.6: Lubricants Selection

2.2.2 Lubrication Regimes

The main purpose of lubrication is to reduce the friction on solid contact surface. This contact can lead to a variety of situations in which different types of fluid films are produced. These include hydrodynamic (HD) lubrication, elastohydrodynamic (EHD) lubrication, mixed lubrication, and boundary lubrication. (Basiron et al., 2023)

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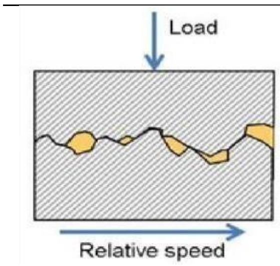
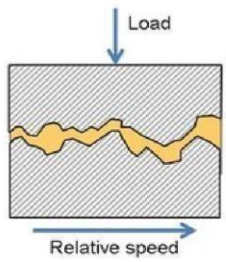
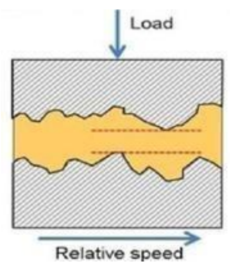
Table 2.2: Illustration of the boundary, mixed and hydrodynamic friction regimes

Boundary Friction	Mixed Friction	Hydrodynamic Friction
		
Even in the presence of fluid, the two surfaces are mostly in contact with each other.	Two surfaces are partly separated, partly in contact.	Two surfaces are separatedby a fluid film.

2.2.2.1 Hydrodynamic Lubrication (HD)

This state of lubrication occurs between sliding surfaces when a full oil film supports and creates a working gap. For the successful and complete application of hydrodynamic lubrication, there must be a high degree of geometric consistency between machine parts and relatively low contact pressures between surfaces in relative motion, such as 100 to 300 psi for industrial journal bearings, which require Relatively low contact pressure prevents greater friction. The lubricating film of hydrodynamic lubrication is usually thicker than the height of the surface irregularities (typically 5-500 µm), so solid-state contact does not occur. The CoF can be as small as 0.001 but it will increase slightly because of the viscous drag. However, lubricant interaction with the surface causes corrosive wear as well as adhesive wear that happens during start-stop operations. In this case, the oil should have the proper viscosity to separate the metal surface. To reduce inner fluid friction, lubricants with the lowest proper viscosity must be used. One of the important additives is antioxidants.

The principal of hydrodynamic bearing is shown in Figure 2.7. Initially, the shaft is stationary and sinks to the bottom of the interstitial space under load. As the journal begins to rotate, it climbs up the bearing surface. As the velocity increases further, it will force the fluid into a region of high pressure (wedge-shaped area).

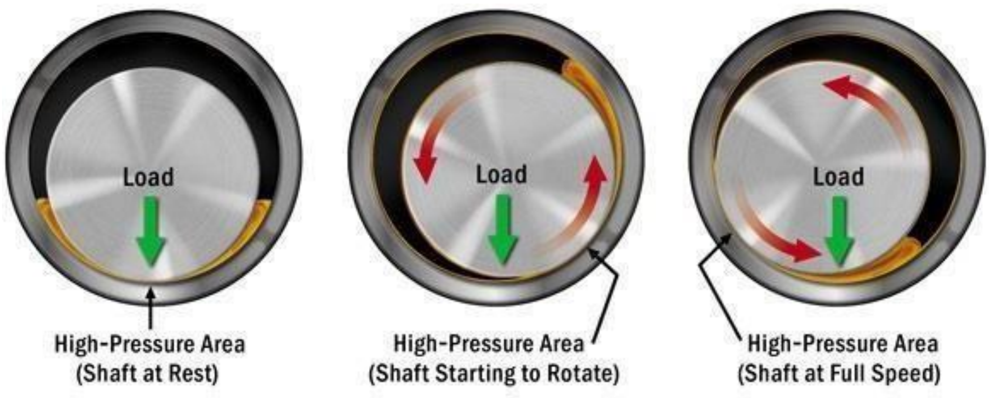


Figure 2.7: Formation of Continuous Film in a Journal Bearing

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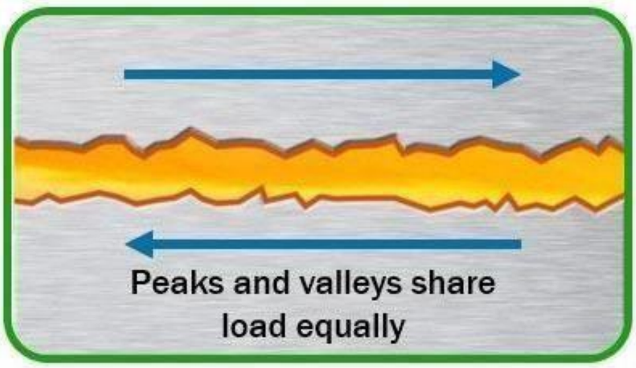

Figure 2.8: Hydrodynamic Lubrication

2.2.2.2 Elastohydrodynamic Lubrication (EHD)

Elastohydrodynamic lubrication is the subset of hydrodynamic lubrication, which the elastic deformation of the contacting solids plays a significant role in the hydrodynamic lubrication process. The film thickness of elastohydrodynamic lubrication is thinner (typically 0.5-5µm). In heavily loaded contacts, high pressures can lead to both changes in the viscosity of the lubricant and elastic deformation of the bodies in contact. Therefore, the surface finish must be of high quality to prevent metal-to-metal contact. Examples of types of lubrication can be seen in gears, rolling contact bearings, cams, etc. The oil must have the correct viscosity under these conditions, and additives can be included to increase the shear stability of the oil.

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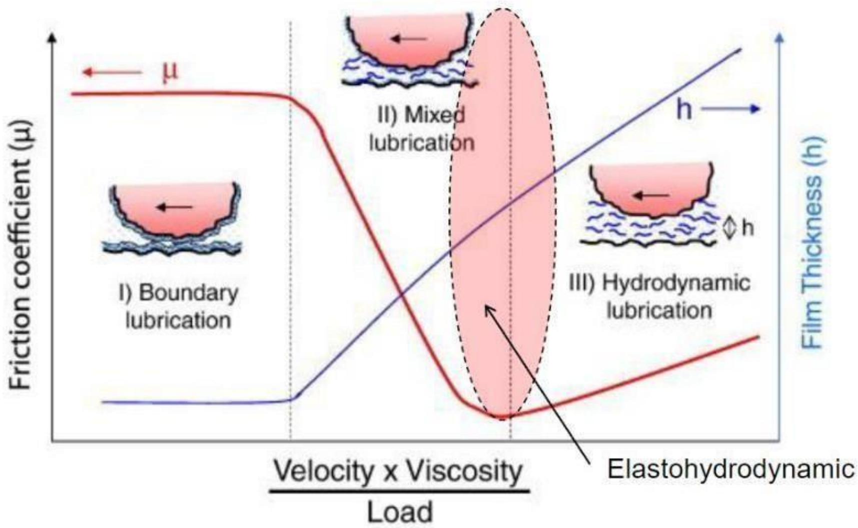

Figure 2.9: Stribeck Curve

2.2.2.3 Mixed Lubrication

Mixed lubrication is a transition between hydrodynamic/elastohydrodynamic lubrication and boundary lubrication regimes, containing features of both. The film thickness typically 0.025-2.5μm. The potential for asperity contact is reduced and film thickness is increased compared to boundary lubrication regimes. They may be more frequent solid contacts, but at least a portion of the bearing surface remains supported by a partial HD film. Thus, the surface wear is mild. Solid-state contact between unprotected metal surfaces can lead to cycles of adhesion, metal transfer, wear particle formation, and eventual seizure. However, in liquid lubricated, chemically reacted film prevents adhesion during most asperity encounters. COF is typically between 0.004 and 0.10. In this case, the oil should have the proper viscosity, include antiwear additives to assist avoid contact between metals, and contain antioxidants to extend the life of the oil.

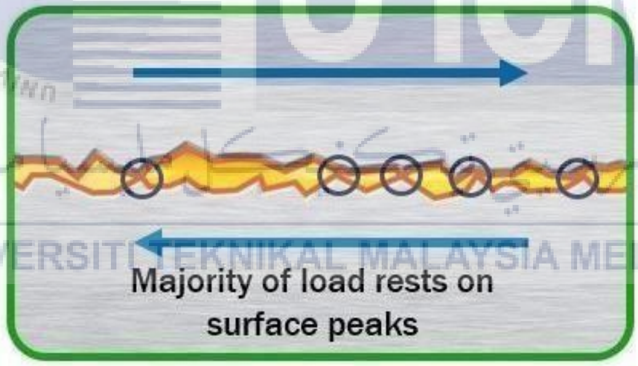

Figure 2.10: Mixed Lubrication

2.2.2.4 Boundary Lubrication

Boundary lubrication involves metal-to-metal contact between two sliding surfaces of a machine. This regime takes place when start-up, high loads or low speed and can influence bearing, gear, as well as cylinder. In this state, two connecting surfaces start to shift toward each other and are in touch. In the change from static to moving, the metal’s surface roughness is contacted, outcoming adhesive wear. The oil film thickness for boundary lubrication ranges between 0-2.0μm. The typical coefficient of friction is 0.05 to 0.2. The higher the coefficient of friction value, the greater the frictional forces. In this case, the oil should be in proper viscosity and if boundary conditions predominant, usually include antiwear additives to assist avoid the contact between two metals.

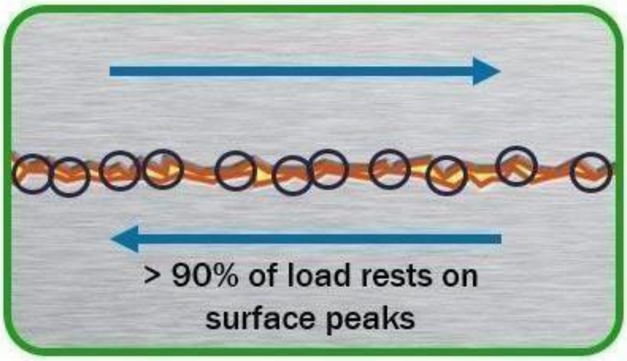

Figure 2.11: Boundary Lubrication

2.2.3 Advantages of Lubrication

Lubrication has many benefits besides reducing friction and wear rates, such as reducing instant failures, fatigue failures, surface failures, and stress concentrations. Additionally, lubrication can be used to isolate moving parts in the system. The benefits of this are reduced friction and surface fatigue, as well as reduced heat generation and running noise. Also, it can be used for heat transfer. Both gas and liquid forms can transfer heat, but lubricants in liquid form are more effective due to their high specific heat capacity. In addition, lubrication has the advantage of sealing the gas. This is because lubricants occupy the gaps between moving parts through capillary forces, thereby sealing the gaps. This effect can be used to seal pistons and shafts. Lubrication also prevents corrosion. High-quality lubricants often contain additives that form chemical bonds with surfaces to prevent corrosion and rust. Since lubricating oils may contain antiwear or extreme pressure additives, their antiwear and antifatigue properties can be enhanced. Moreover, lubrication carries away contaminants and debris. The benefit of a lubricant circulation system is that it removes debris which generates from the inner and contaminants from the external. These

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contaminants and debris enter the system and enter the filter, then they will be removed.

2.2.4 Application of Lubrication

Compelled by rapid industrialisation and growth of the automotive sector, demand for lubricants in various applications (Figure 2.12) is continuously increasing each year.

Figure 2.12: Various field of applications of lubricants

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Lubrication can be used for transmission components, bearings, cams, journals, sealing surfaces and anywhere that involves metal-to-metal contact. It can be used industrially as hydraulic oil, air compressor oil, food-grade lubricating oil, gas compressor oil, gear oil, bearing and circulation system oil, steam and gas turbine oil, as well as refrigerator compressor oil. (Armylisas et al., 2018)

2.3 Nanoparticle

According to Wikipedia, nanoparticles or ultrafine particles are generally defined as particles of matter between 1-100 nanometers (nm) in diameter. The term is sometimes used for larger particles, which diameter is up to 500 nm, or tubes and fibers with diameter smaller than 100 nm in only two directions. Nanoparticles are generally distinguished from microparticles (1-1000 µm), "fine particles" (size range from 100 to 2500 nm), and "coarse particles" (range from 2500 to 10,000 nm) because their smaller size drives distinct physical or chemical properties such as colloidal properties and ultrafast optical effects or electrical properties. Nanoparticles, characterized by their small size and very large surface-to-volume ratio, have unexpected optical, physical, and chemical properties because they are small enough to limit electrons and produce quantum effects.

Table 2.3: Size of Nanoparticles compared to other structures

Particle Type	**Diameter Size Range**
Atoms and small molecules	0.1 nm
Nanoparticles	1-100 nm
Fine particles (also called particulate matter-$PM_{2.5}$)	100-2500 nm
Coarse particles (PM_{10}, or dust)	2500-10000 nm
Thickness of paper	100000 nm

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2.3.1 Current nanoparticles as additives

Nanoparticles have excellent Young's modulus, stress and strain properties, as can be seen from their mechanical properties, they can provide many applications in the mechanical industry, especially in coatings, adhesives, and lubricants applications. Besides, nanomaterials are used as lubricating oil additives. Due to their small size, they can easily enter the friction contact area and form a protective friction film, thus preventing the surface wear of the friction pair. Moreover, nanoparticles have good sliding and delamination properties, which can also reduce friction and wear, thereby improving the lubrication effect (Khan et al., 2019).

Therefore, nanoparticles can be used as additives to improve the performance and efficiency of bio-lubricants by enhancing their lubrication properties and reducing friction and wear.

There are three primary types of nano-lubricant additives which are nanometal-based additives, nanocarbon-based additives, and nanocomposite-based additives, as shown in Table 2.4. The nanometal-based lubricant additives can be classified into pure metal, metal oxide, metal sulphide, metal hydroxide, and metal salt. Whereas nanocarbon-based lubricant additives consist only of pure carbon and chemical element-based polymers. Compared with nano-metal- based and nano-carbon-based additives, nano-composite-based additives have outstanding lubricating properties, because the additives can form a composite friction film at the friction interface and have a synergistic lubricating effect.

Table 2.4: Types of Nano-lubricant additives (Zhao et al., 2021)

Types of Nano-lubricant Additives		**Examples**
Nanometal-based lubricant additives	Pure metal	Cu, Ag, Fe, Pd, Ni
	Metal oxide	CuO, ZnO, Al2O3, TiO2, ZrO2
	Metal sulphide	WS2, MoS2, CuS, ZnS
	Metal hydroxide	La(OH)3, LDHs
	Metal salt	CaCO3, LaF3, ZrP, Calcium Borate, Zinc Phosphate
Nanocarbon-based lubricant additives	Pure carbon	Nano Diamond, Fullerenes, Carbon Nanotubes, Graphene
	Polymer	PTFE, PSS, PVP

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Nanocomposite-based lubricant additives	Cu@SiO2, Al2O3@TiO2, Cu@MoS2, G@MoS2, α-Fe2O3@GO, FeS2@G, Ag@G, Cu@GO, Mn3O4@G, La2O3@PI, Alumina@MWCNT

2.3.2 Ingredients contained in Scallop-Shell

Scallop (scientific name: Pectinidae) is the common name that encompasses various species of marine bivalve mollusks. Scallops are a cosmopolitan family of bivalves found in saltwater environments like the Atlantic Ocean. The shell of a scallop consists of two sides or valves, a left valve and a right one, divided by a plane of symmetry. It consists of two similarly shaped valves with a straight hinge line along the top, devoid of teeth, and producing a pair of flat wings or "ears" on either side of its midpoint, a feature which is unique to and apparent in all adult scallops. Shell is the exoskeleton of scallop, and it is not made up of cells. The shell has three different layers and is mainly composed of calcium carbonate with only a small amount of protein (≤2%). Most scallops are free-swimming, they swim by clapping their shells quickly using their highly developed adductor muscle, forcing a jet of water past the shell hinge, propelling the scallop forward (Kennedy, 2020).

Figure 2.13: Scallop-Shell

2.3.3 Potential of using Scallop-Shell nanoparticle as additives

The chemical components of scallop-shell powder consist of CaO, SiO_2, Al_2O_3, and Fe_2O_3. The percentages of chemical components in scallop-shell powder are shown in Table 2.5 (Her et al., 2021). Calcium oxide is the major composition of scallop-shell powder. Calcium oxide is a compound with the chemical formula CaO, which is a substance commonly found in rocks such as calcite and aragonite, most notably chalk and limestones, gastropod shells, eggshell, shellfish bones and pearls.

For using scallop-shell nanoparticle as additives, calcium oxide is intended to detach impurities and keep them in suspension. Besides, calcium oxide can be used as a lubricating oil additive to improve the wear resistance of the lubricating oil, but it cannot improve the anti- friction performance of the lubricating oil (Arinbjarnar et al., 2022). Smaller particles can be used to stabilize the contact interface. Hence, scallop-shell nanoparticles can be used as an additive for bio-lubricant to let the performance of bio-lubricants oil become better and efficient by enhancing their lubrication properties.

Table 2.5: Chemical Properties of Scallop-shell Powder

Chemical Components	Value (%)
CaO	53.72
SiO_2	0.28
Al_2O_3	0.12
Fe_2O_3	0.02

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2.4 Tribological Properties

According to Wikipedia, tribology is the science and engineering of interacting surfaces in relative motion. Tribological properties refer to the study and characterization of friction, lubrication and wear. It encompasses the understanding of how surfaces interact with each other and the effects of friction and wear on the performance and durability of materials and systems. Tribological properties play a significant role in numerous industries, including automotive, aerospace, manufacturing, energy, and biomedical, where minimizing friction, wear, and lubrication-related issues is essential for improving the efficiency, reliability, and lifespan of components and systems.

2.4.1 Friction

Friction is the force that prevents two surfaces from sliding or rolling against each other. Factors that affect friction involve:

- Finish or roughness of the surface: Microscopic surface asperities must slide or roll over each other in order to achieve motion.
- Temperature, load, and speed: High temperatures, higher loads, as well as slower speeds have a big influence on friction.
- Rolling and sliding motion: Losses of friction are caused by these two forces.
- Characteristics of lubricating oil: For example viscosity and the content of additive.

There are several types of friction shown in Table 2.6.

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Table 2.6: Types of Friction (MajorFlower2187 et al.,2020)

Type of friction	Description
Dry friction	The force resisting the relative lateral movement of two contacting solid surfaces. There are two types of dry friction, static friction between non-moving surfaces and kinetic friction between moving surfaces.

Fluid friction	Friction between layers of viscous fluid in relative movement.
Lubricated friction	The case of fluid friction in which a lubricant fluid separates two solid surfaces.
Skin friction	A component of drag, the force resisting a fluid’s motion across a body’s surface.
Internal friction	When a solid material is deformed, the force that resists the motion between the elements that make up the solid material.

2.4.1.1 Dry Friction

When two dry surfaces move or tend to move relative to one another, there is tangential contact force that is known as "dry friction." The two types of dry friction are kinetic friction (sometimes referred to as sliding friction or dynamic friction) between moving surfaces and static friction ("stiction") between stationary surfaces. Coulomb friction is used to calculate the dry friction force.

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$$\boldsymbol{F_f \leq \mu F_n}$$

- F_f - parallel friction force exerted in opposite direction to the force applied.
- μ - CoF, depends on the properties of the contact material.
- F_n – normal (also known as perpendicular force) applied to the surface.

Table 2.7: Laws of dry friction

LAWS OF DRY FRICTION	DESCRIPTION
AMONTONS' FIRST LAW	Friction is directly proportional to the applied load

AMONTONS' SECOND LAW	Friction is independent of the apparent contact area.
COULOMB'S LAW OF FRICTION	Kinetic friction is not dependent on sliding velocity.

2.4.1.2 Fluid Friction

According to Wikipedia, fluid layers moving relative to one another experience fluid friction. The term viscosity refers to this internal flow resistance. In daily parlance, the “thickness” of a fluid is described as the viscosity of a fluid. Therefore, because water is "thin," it has a lower viscosity than honey, which is "thick". Low viscous fluids are easier to deform or move, while high viscous fluids offer greater resistance to deformation and movement.

All real fluids have some shear resistance and are therefore vicious. It is helpful to use the concept of an inviscid fluid or an ideal fluid that offers no shear resistance and is therefore not viscous.

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2.4.2 Coefficient of Friction

Friction is expressed as a coefficient, it is usually indicated by the Greek letter mu (μ), equal to the forces of sliding or rolling (F) divided by the load (N) placed,

$$\mu = F/N$$

The CoF ranges is between 0-1. The higher the value of μ, the larger the friction. (Wypych, 2023)

2.4.3 Wear

Wear is the deformation, slow removal or destructive of solid surface material. The wear can be caused by mechanical or chemical, such as erosion and corrosion respectively. The research of wear and related processes is known as tribology.

The wear rate is affected by type of load (e.g. impact, static, dynamic), type of movement (e.g. sliding, rolling), temperature, and lubrication, in particular through the deposition and wear processes of the boundary lubricant layer. Distinct wear types and wear mechanisms can be inspected depending on the tribosystem.

2.4.3.1 Wear Mechanism

The wear mechanism is a physical interference. For instance, adhesion is the mechanism of adhesive wear. Besides, abrasive wear and fatigue wear are also the principal types of wear mechanisms. Wear mechanism can be analysed by using scanning electron microscopic (SEM).

Abrasive wear happens when hard particles or a rough surface rub against a soft surface, whereas adhesive wear happens when two nominally flat solid bodies are in sliding contact. In general, abrasive wear results in more wear than adhesive wear. On the other hand, fatigue wear is a type of wear in which the material's surface is damaged as a result of tension applied to it for a predetermined number of cycles up to a predetermined critical limit.

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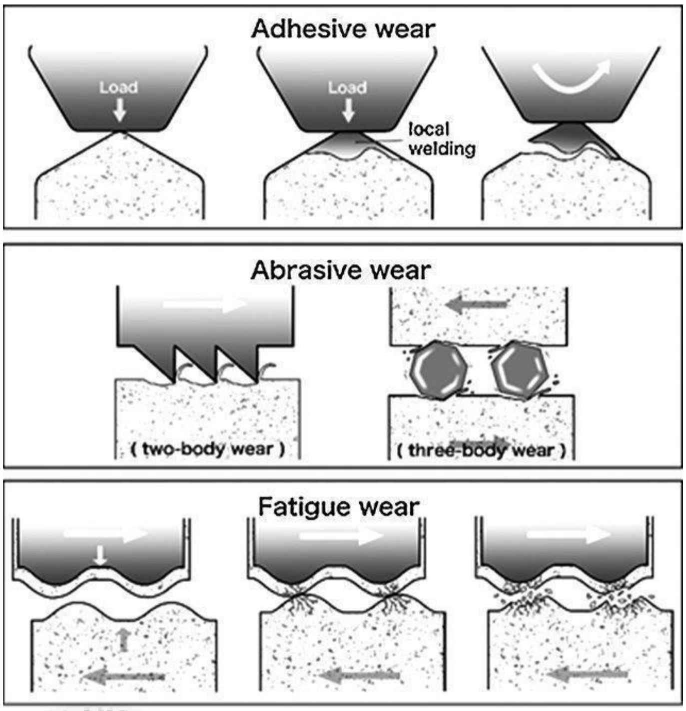

Figure 2.14: Mechanisms of wear in general: adhesive wear; abrasive wear; fatigue wear. (Tsujimoto et al., 2018)

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CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter contains about the explanation of the methodology process that will be carried out in the experiment. The reason is to make sure that the aim of this research can be successfully accomplished. The content includes the preparation of waste Musa Paradisiaca, extraction of oil, as well as preparation and incorporation of scallop-shell nanoparticles. In addition, procedures for bio-lubricant performance testing using a four-ball tester according to ASTM D4172 and surface analysis using SEM to determine the wear scars and wear rates to analyse tribological behaviour are presented.

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The process begins with material selection. The banana peel of Musa Paradisiaca is used as raw material for new bio-lubricant, it will be blended with an optimized composition of scallop-shell nanoparticles. Banana oil and scallop-shell nanoparticles will be mixed by using Ultrasonic Homogenizer. If the bio-lubricant performance test (four-ball test with ASTM D4172) fails, it will go back to infuse scallop-shell nanoparticles with banana extracted oil with different weightages of nanoparticles. If the bio-lubricant performance test success, the sample will then be evaluated with Scanning Electron Microscope (SEM) for wear mechanism to identify the wear scar diameter.

3.1.1 Flow chart

The project flow chart is shown in Figure 3.1. The flow chart described the end-to-end process for development of bio-lubricant from waste Musa Paradisiaca enhance by crystalized structure of scallop-shell nanoparticles. First, collection and preparation of Musa Paradisiaca. Second, extraction of oil from Musa Paradisiaca peels by using Soxhlet Extraction Fat Analyzer SZF-06A machine. Third, preparation of scallop-shell nanoparticles. Fourth, infusing scallop-shell nanoparticles into the extracted oil by using Ultrasonic Homogeniser. Next, conduct a four-ball test according to ASTM D4172. If the test succeeds, proceed to evaluate the wear mechanism by using Scanning Electron Microscope (SEM).

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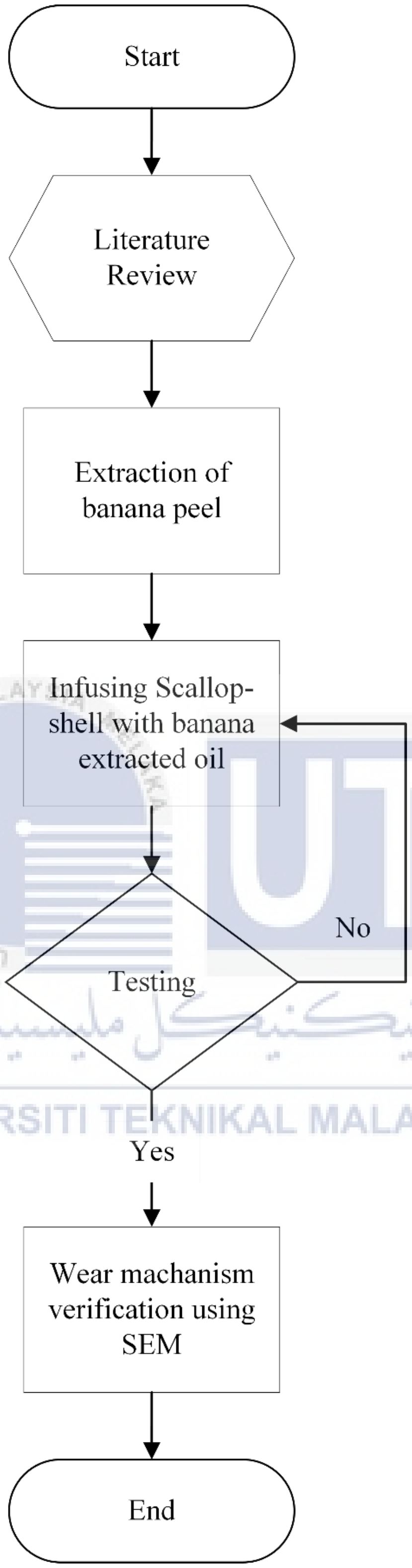

Extraction of banana oil by using Soxhlet Extraction Fat Analyzer SZF-06A machine.

Infusing scallop-shell with banana oil by using Ultrasonic Homogeniser.

Testing involved of tribological testing that will be conducted according to ASTM D4172 by 4-ball Tribotester which details explained in Methodology 3.6.1.1.

The Wear mechanism will be evaluated after surface morphology has been conducted using SEM.

Figure 3.1: Flow Chart

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3.2 Collection and Preparation of Waste Musa Paradisiaca

Banana peels (ripe) obtained as agro- or domestic waste, will be collected from stall, washed under clean water and air-dried until a constant mass is recorded. Once dried, it needs to be crushed using a pestle and mortar to provide a larger surface area for more efficient oil extraction. Then, put in the Soxhlet Extraction Fat Analyzer SZF-06A machine and use hexane to extract the banana oil. Leave 3-5 hours to extract the banana oil. Lastly, the extracted banana oil can be obtained.

3.2.1 Characterization of Musa Paradisiaca

Musa paradisiaca, also known as plantain or banana, is a tropical fruit tree belonging to the Musaceae family. It is native to Southeast Asia but is now widely cultivated in many tropical regions worldwide. It is characterized by its large herbaceous plant with a pseudostem. The fruit of Musa paradisiaca is elongated, with a thick green or yellowish skin that turns black when fully ripe. It is commonly used in cooking and is known for its starchy nature. Plantains are a staple food in many tropical regions, providing vitamins, potassium, and dietary fiber. They are cultivated in tropical climates and contribute to local economies as an important crop in various industries.

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Figure 3.2: Banana

According to IOP Conference Series: Earth and Environmental Science, proximate analysis is a method of chemical analysis for the determination of the nutritional content of ingredients.

The proximate analysis results of fruit flesh, skin flour and bananas can be seen in Table 3.1. Banana peel flour has the highest moisture content compared to its flesh and fruit, which is because of the peel content high tannin. Besides, the banana peel also has the highest fat element compared to flesh and fruit, which is 5.54%, and it is the lowest in fruit flesh, which is only 0.18%. The calculated value of the remaining not organic material during the ashing process is known as the ash element. The starch texture and colour will be affected by the ash element. Banana flesh and fruit have nearly the same amount of protein, 2.03% and 2.04%, respectively. According to SNI standards, the protein content obtained in this study was still low at 7 percents. But the nutrient content of the banana flesh, peel and fruit indicates a good source of nutrition.

Table 3.1: Proximate analysis of banana flour from banana flesh, peel, and fruit(Syukriani et al., 2021)

Part of fruit	**Moisture (%)**	**Fat (%)**	**Ash (%)**	**Protein (%)**
Flesh	6.21 ± 0.58	0.18 ± 0.13	1.81 ± 0.55	2.03 ± 0.09
Peel	9.33 ± 0.43	5.54 ± 0.30	1.86 ± 0.26	2.10 ± 0.18
Fruit	6.48 ± 1.07	2.07 ± 0.19	1.33 ± 0.30	2.04 ± 0.10

3.2.2 Musa Paradisiaca Part Selection

Banana peel is the most suitable part to extract oil. Among the main components of banana peel are organic matter, minerals, carbon, follicular gel (pectin), tannin, etc. When banana peel waste was examined morphologically, a mixture of follicular gel (pectin) formed, which led to the presence of oil. In this report, the follicular gel in the banana peel will be used for oil extraction. The details for follicular gel can be found in Literature review 2.1.3.

Figure 3.3: Banana peel

3.3 Extraction of oil

Extraction of oil is extracting essential oils or compounds present in the banana peels through a process. In this process, the dried banana peels will be extracted into oil in a machine for several hours. Banana peel oil extraction involves breaking down the peels and separating the oil or aromatic compounds from the solid material.

Soxhlet Extraction Figure 3.4 is a time-honoured method in which a sample is placed in a thimble holder and progressively filled with concentrated fresh extractant (the solvent used for extraction) from a distillation flask. It is one of the oldest concrete sample preparation techniques (Putra et al., 2022).

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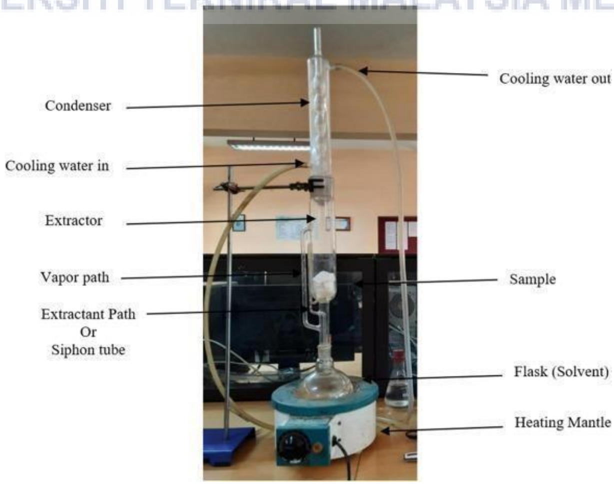

Figure 3.4: Soxhlet Extraction (Rajesh et al., 2023)

3.3.1 Machine Extract Oil

However, in this report Soxhlet Extraction Fat Analyzer SZF-06A machine (Figure 3.5) will be used to extract the banana oil. This machine is a more advanced fattiness analysis technology and has a lot of advantages. For example, it has small volume, fast in temperature rise, and uniform in heating. Also, the extraction bottle and apparatus are made of glass to avoid other spills. Furthermore, it has accurate digital temperature control for easy operation. We just need to set up the machine and put crushed banana peel and ethanol to extract the banana oil. Then, leave it until the next day to collect the extracted banana oil.

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Figure 3.5: Soxhlet Extraction Fat Analyzer SZF-06A

3.3.2 Characterization of the Extracted Oil

The extracted oil can be characterized based on its composition, physical properties (colour, odour, taste), chemical properties (acidity, peroxide value, iodine value), nutritional profile (essential fatty acids, vitamins), stability (oxidation resistance), and microbiological quality (microorganism presence). These characterizations help assess the oil's quality, application suitability, and potential health benefits. By determining these aspects, one can comprehensively understand the extracted oil, its properties, and its potential applications. Banana peel extract (BPE) is composed of crude fat (3.8 to 11%), total dietary fibre (43.2 to 49.7%), crude protein (6 to 9%), starch (3%), pectin, micronutrients (Mg, K, Ca, P), polyunsaturated fatty acids, and amino acid. Moreover, the physical properties of BPE is shown in Table 3.2.

Table 3.2: Physical Properties of BPE (Amodu et al., 2022)

Physical properties	Value
Density	1.56 g L^{-1} cm^{-3}
Viscosity	32.04 cp
Surface tension	18.0 dynes cm^{-1}
Specific gravity	1.55
Flash point	273 ℃

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According to the Malaysian Journal of Halal Research, analysis of phytochemicals in the ethanol extract of banana peel revealed flavonoids, carbohydrates, reducing sugars, tannins, saponins, alkaloids and phenols (Kibria et al., 2019).

3.4 Preparation of Scallop-Shell Nanoparticles

Bio-lubricant oil made up of two compositions which are base oil and additive. In this report, scallop-shell nanoparticles will be used as the additive for developing the bio-lubricant oil. Preparation of Scallop-Shell nanoparticles is the process of synthesizing or creating nanoparticles from the Scallop-Shell. These nanoparticles have potential applications in bio-lubricant and can affect the performance of bio-lubricant. In addition, particle size also affects the performance of bio-lubricants. This is because the smaller size facilitates access to the area of frictional contact and creates a protective friction film that prevents wear on the surfaces of the friction pair.

3.4.1 Characterization of Scallop-Shell Nanoparticles

Scallop-shell nanoparticles are nanostructures of a scallop-shell. The main component of untreated scallop-shell was calcium carbonate, $CaCO_3$. Characterization of scallop-shell nanoparticles includes analysis of their size, shape, composition, surface properties, and response behaviour. The physical and chemical characteristics of these nanoparticles are frequently investigated using methods like dynamic light scattering, spectroscopy, scanning electron microscopy (SEM), and transmission electron microscopy (TEM).

The addition of calcium carbonate can influence the viscosity of the bio-lubricant oil. Moreover, calcium carbonate can act as solid lubricants, helping to reduce wear between two contacting surfaces. Calcium carbonate also can potentially improve the thermal stability of the bio-lubricant oil.

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3.4.2 Procedure of synthesis Scallop-Shell Nanoparticles

First, the scallop-shells need to be collected at the seashore. After that, clean and ground the collected scallop-shell. Calcinate it under high temperature to convert it into calcium oxide. Next, mill the particles into small sizes and undergo surface modification. Lastly, mix with the base oil by using ultrasonic homogenizer.

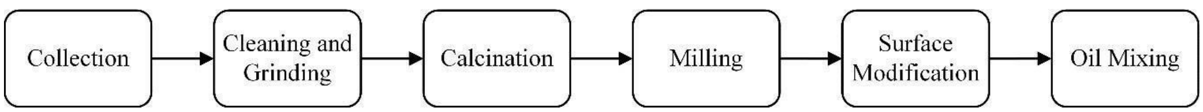

Figure 3.6: Process of Preparation Scallop-Shell Nanoparticles

Table 3.3: Process Detail Description

Process	Descriptions
Collection	Scallop-shells are gathered from the shore or obtained from seafood processing plants.
Cleaning and Grinding	The collected shells are thoroughly cleaned to remove any impurities. They are then ground into smaller pieces or powdered form using mechanical methods.
Calcination	The ground scallop-shells are subjected to high temperatures in a process called calcination. This step helps remove organic matter and converts the shells into calcium oxide (CaO).
Milling	The calcium oxide obtained from the calcination process is further milled to reduce particle size and enhance surface area.
Surface Modification	Scallop-shell nanoparticles can be surface modified to improve their compatibility and dispersion in extracted oils. This can involve treating the nanoparticles with appropriate surfactants or chemical modifications.
Oil Mixing	The modified scallop-shell nanoparticles are added to the extracted oil. They can act as additives to enhance the oil's properties, such as viscosity, stability, or lubrication.

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3.5 Incorporation of Scallop-Shell Nanoparticles

The incorporation of nanoparticles into bio-lubricant oil refers to the adding certain substances called additives to the ingredients of bio-lubricating oil. Eco-friendly lubricants known as "bio-lubricants" are made from synthetic esters or vegetable oils, which are renewable resources. Additives are mixed with lubricants to enhance their performance characteristics and provide additional benefits. For example, oxidation stability, anti-wear properties, corrosion resistance, viscosity index, and thermal stability. Additives can also help to reduce friction, improve lubricity, and improve the overall effectiveness of the lubricant.

The incorporation of scallop-shell nanoparticles is the process of adding tiny scallop-shell particles to the bio-lubricant oil formulation. These nanoparticles are designed to enhance the performance and properties of the bio-lubricant. Ultrasonic homogenizer will be used in the incorporation process to reduce the small particles in liquid. Ultrasonication process can improve the stability and uniformity of the mixture.

3.5.1 Sizes for Nanoparticles added

Generally, nanoparticle loadings in bio-lubricant formulations range from 0.1 vol% to 30.0 vol% by weight, depending on the specific nanoparticles and their intended effects (MacRae, 2022). In this report, 4 experiments will be performed using samples A to D with the sizes of scallop-shell nanoparticles being no $CaCO_3$, micro $CaCO_3$, nano $CaCO_3$, and commercial $CaCO_3$, respectively, as shown in Table 3.4.

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Table 3.4: Sizes for Nanoparticles added

Sample	Oil	Size of Scallop-Shell Nanoparticles
A	10 ml	Without $CaCO_3$
B	9.95 ml	0.05 ml Micro $CaCO_3$
C	9.95 ml	0.05 ml Nano $CaCO_3$
D	9.95 ml	0.05 ml Commercial $CaCO_3$

Since the scallop-shell nanoparticles are in powder form, equation of density equal mass per volume can be used to convert powder scallop-shell into volume. The density of scallop-shell is 2.5-2.6 g/cm^3.

$$\text{eq: } d = \frac{m}{v}$$

3.5.2 Ultrasonication Process

The ultrasonication process is a fine mixing of the Scallop-Shell nanoparticles with the banana oil. It can be divided into three types which are ultrasonic homogenizer, pressure homogenizer, and mechanical homogenizer. During ultrasonication, high-frequency sound waves create alternating cycles of high and low pressure in the bio-lubricating oil. These cycles generate tiny bubbles known as cavitation bubbles. As the bubbles rapidly expand and collapse, they create localized regions of high temperature and pressure. This phenomenon induces intense shear forces and turbulence in the bio-lubricant, leading to the breakup of agglomerates or clusters of nanoparticles and promoting their uniform dispersion. With a probe diameter of 3–40 mm, an ultrasonic homogenizer can sonicate samples with volumes ranging from 5–4000 ml. (Basiron et al., 2023).

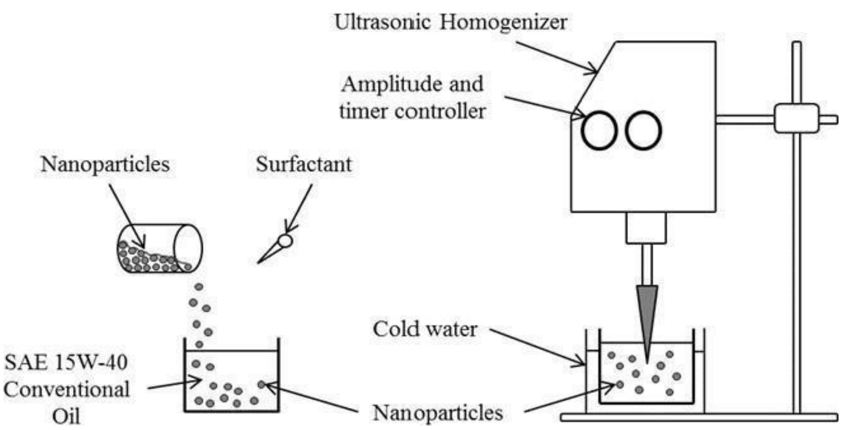

Figure 3.7: Schematic diagram sample preparation by using ultrasonic method (Abdullah et al., 2019)

3.6 Bio-lubricant Performance Test

The purpose of doing a bio-lubricant performance test is to evaluate the effectiveness and efficiency of bio-based lubricants. These tests measure various properties and characteristics of the lubricants to determine their performance under different conditions. The tests may include assessments of viscosity, lubricity, oxidation stability, wear protection, corrosion resistance, and environmental impact. The results help determine the suitability and potential applications of bio-lubricants in different industries and ensure compliance with relevant standards and regulations.

3.6.1 Four-ball Tester with ASTM D4172

Lubrication technology is essential to reduce friction and wear losses in machines. The efficient key of a tribological system is the lubricant, such as grease, oil, and solid lubricant. The four-ball tester, sometimes referred to as the Shell four-ball tester, is used to evaluate lubricating oil characteristics such wear prevention (WP), extreme pressure (EP), and frictional behavior. It is a standardized test method defined by ASTM D-4172. According to Industrial Lubricants, there are many other testing standards as shown in Table 3.5.

Table 3.5: Various test standards performed using a Four Ball Tribometer

TEST STANDARD	**LUBRICANT TYPE**	**TEST**
ASTM D2266	Greases	Wear preventive properties

ASTM D2596, ASTM D2783	Greases	Extreme pressure properties
ASTM D4172	Lubricating fluids	Wear preventive properties
ASTM D5183	Lubricating fluids	Frictional coefficient
IP 300	Lubricating fluids	Rolling contact fatigue
CEC L-45-A-99 (KRL)	Lubricating fluids	Viscosity shear stability of transmission lubricants

The tester consists of four balls in an equilateral tetrahedron structure, as shown in Figure 3.8. The upper ball rotates and contacts the lower three balls that remain in fixed positions.

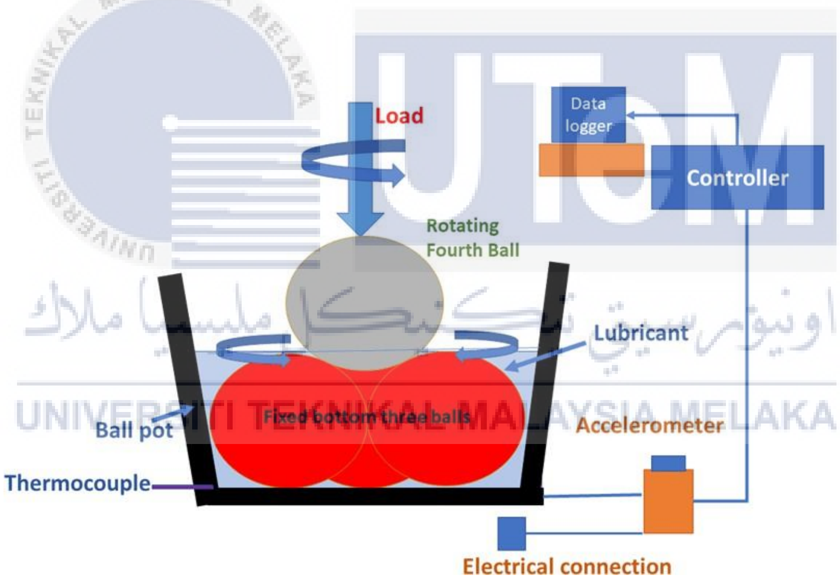

Figure 3.8: Schematic diagram of rolling contact fatigue set up in a four ball tribometer.

3.6.1.1 Four-ball Tester Procedure

In this test, three steel balls are arranged in a triangular formation, and a fourth steel ball is pressed against them with a fixed load and rotational speed. The test oil, in this case, the bio-lubricant, is placed in the test chamber, and the balls are rotated under specified conditions for a predetermined duration. During the test, the rotating balls create friction and wear between them. The test measures various parameters, such as the coefficient of friction, wear scar diameter, and weld point, to assess the lubricating properties and anti-wear performance of the bio-lubricant oil.

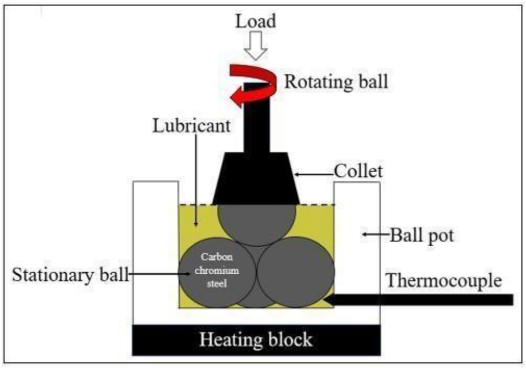

Figure 3.9: Schematic diagram of ball pot assembly (Basiron et al., 2023)

3.7 Surface Analysis

After bio-lubricant performance testing, the surface analysis will be carried out. Surface analysis is the characterization and evaluation of the surface properties and interactions of the lubrication oil at a microscopic level. It involves the use of various analytical techniques to study the composition, structure, morphology, and chemical reactivity of the lubricant oil film that forms on the surfaces in contact.

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By performing surface analysis, we can gain insights into the lubricant's behaviour, such as its adhesion, friction, wear resistance, and ability to protect and reduce damage on the surfaces it lubricates. This information helps in optimizing the formulation and performance of bio-lubricant oils, enhancing their effectiveness and efficiency in lubrication applications while minimizing environmental impact.

3.7.1 SEM

The acronym for scanning electron microscopy is SEM. It's an electron microscope that uses a concentrated electron beam to scan a sample's surface and produce photographs of it. The sample's atoms and electrons interact to produce a variety of signals that provide details on the surface composition and topography. An image is created by combining the intensity of the detected signal with the position of the electron beam as it scans in a raster scan pattern.

In the context of testing the surface analysis of bio-lubricant oil, SEM can be employed to examine the surface characteristics of the oil. It can provide high-resolution images of the oil's surface, allowing for the observation of features such as particle size, shape, distribution, and any surface irregularities or defects. Additionally, SEM can help identify contaminants or impurities present on the surface of the oil, which is crucial for assessing the quality and performance of the lubricant.

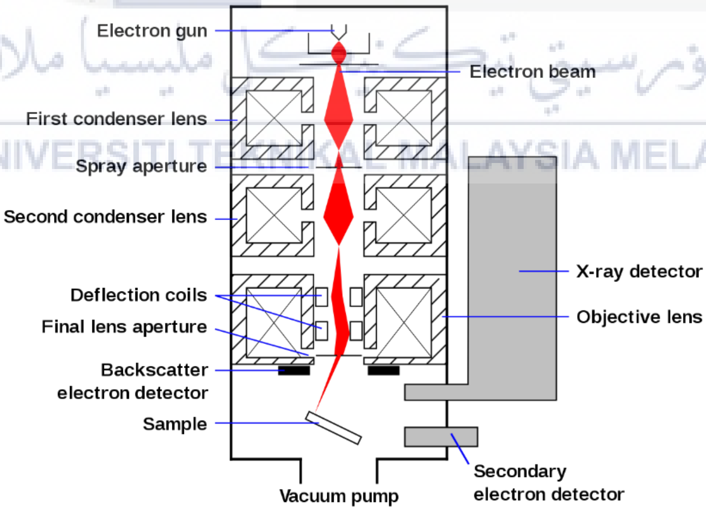

Figure 3.10: Schematic of an SEM

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CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter explains and discusses the results of experiments on the extraction of bio-lubricants from banana peels. Experiments produce results and display data in graphs and tables. The first experiment analyzed the effect of banana peel oil on Coefficient of Friction (CoF) using a four-ball tester accordance with ASTM D-4172. Next, the steel balls from the four-ball test were analyzed to determine Wear Scar Diameter (WSD) and Scanning Electron Microscope (SEM).

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4.2 Effect of additive on the Wear Scar Diameter (WSD) and Coefficient of Friction (CoF)

Banana peel oil samples containing four different particle size additives were prepared using an ultrasonic homogenizer. The mechanical technique of reducing particles in a liquid to a uniformly small and evenly dispersed size is known as ultrasonic homogenizer. These effective instruments are used to blend and homogenize liquid-liquid and solid-liquid mixtures (Ultrasonics, 2023). According to TriboNet, oil lubrication and related lubrication technologies are crucial for lowering wear losses and friction in machinery. Hence, the samples were tested on a four-ball testing machine at a fixed temperature, speed, load, and time to analyze the tribological properties of the bio-lubricant. The Four Ball Tester, sometimes referred to as the Shell Four Ball Tester, is a tool used to evaluate the characteristics of lubricants, including frictional behavior, extreme pressure (EP), and wear prevention (WP) (TriboNet, 2022). The main purposes of adding additives to base oils are to enhance existing base oil properties, suppress undesirable base oil properties, and impart new properties to base oils (Corporation, 2018). In this experiment, additives were added to reduce the friction coefficient of the mechanical system. The observed parameters are wear scar diameter (WSD) and friction coefficient (CoF). All results were measured at 75°C temperature, 2500 rpm, 392.4 N load and 30 minutes in accordance with ASTM D-4172.

Table 4.1 shows the wear scar diameter (WSD) and coefficient of friction (CoF) of banana peel oil (Samples A to D) with different particle size additives, where sample A is 100% banana peel oil, Sample B is banana peel oil + micro $CaCO_3$, Sample C is banana peel oil + nano $CaCO_3$, and Sample D is banana peel oil + commercial $CaCO_3$. The average WSD of Sample A, B, C, and D are 1.47, 0.77, 0.69, and 0.67 respectively. Moreover, the CoF of Sample A, B, C, and D are 0.13794, 0.10102, 0.10176, and 0.08385 respectively. Figure 4.25 illustrates the comparison of CoF of banana peel oil with different particle size additives. It can be observed that Sample D (banana peel oil + commercial $CaCO_3$) has the best CoF result of only 0.08385, while Sample A (100% banana peel oil) has the worst result in CoF, which is 0.13794. According to Wikipedia, the coefficient of friction (CoF) is a numerical representation indicating the connection between two objects and the perpendicular force exerted between the respective objects. Typically ranging from 0 to 1, the coefficient of friction can exceed 1. A 0 value denotes the absence of friction between objects, while a value of 1 signifies equal frictional and normal forces. Consequently, a lower coefficient of friction indicates reduced friction and enhanced lubrication performance. This means that Sample D is the best bio-lubricant because it has the lowest CoF value compared to samples A, B and C.

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Table 4.1 Results of banana peel oil with different sizes of additive

Sample	Applied Load (kg)	Load (N)	Speed (rpm)	WSD (mm)			Average WSD	COF
				1	2	3		
A	40	392.4	1200	1.46	1.48	1.48	1.47	0.13794
B	40	392.4	1200	0.77	0.77	0.76	0.77	0.10102
C	40	392.4	1200	0.69	0.69	0.70	0.69	0.10176
D	40	392.4	1200	0.67	0.67	0.67	0.67	0.08385

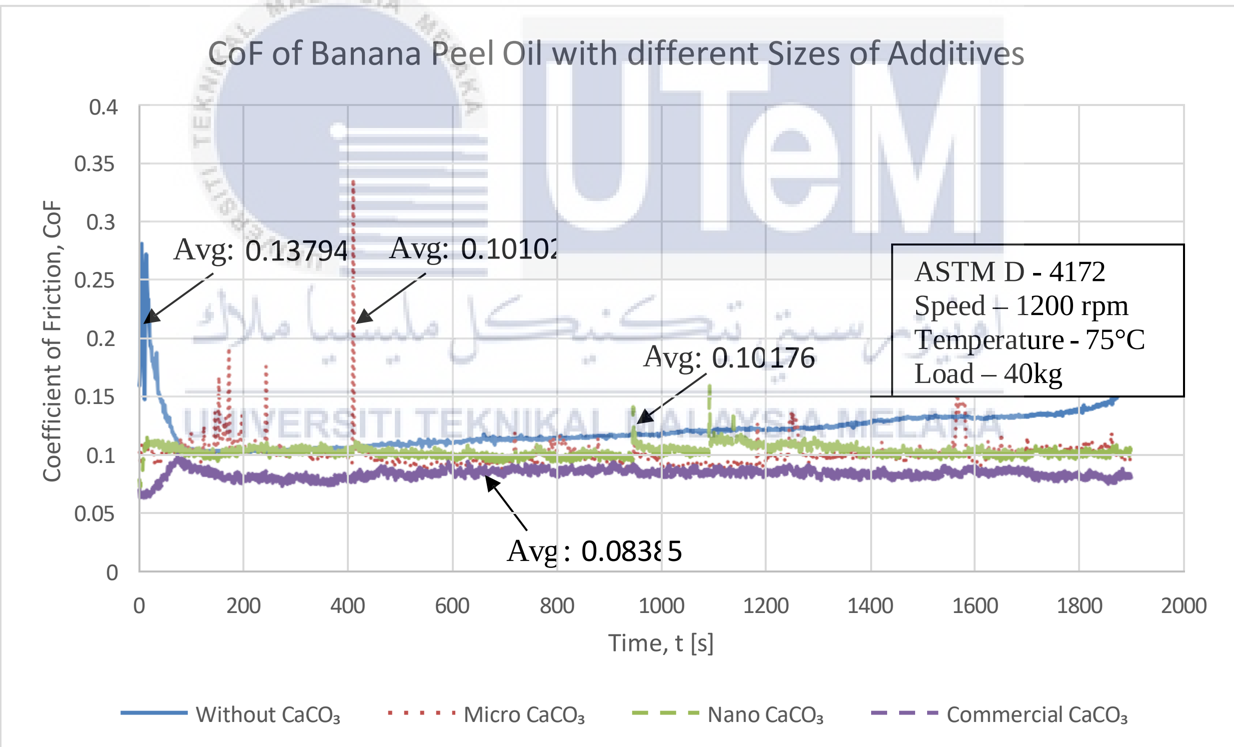

Figure 4.1 Comparison of CoF of banana peel oil with different sizes of additive

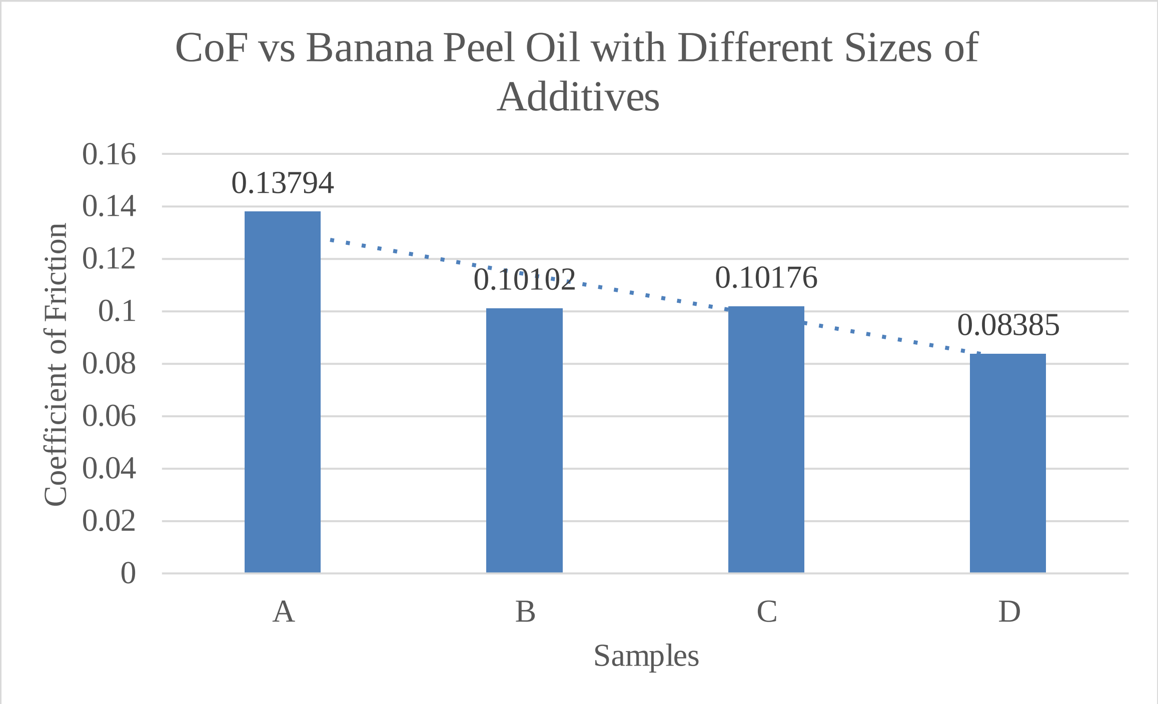

Figure 4.2 Graph of CoF vs Banana Peel Oil with Different Sizes of Additives

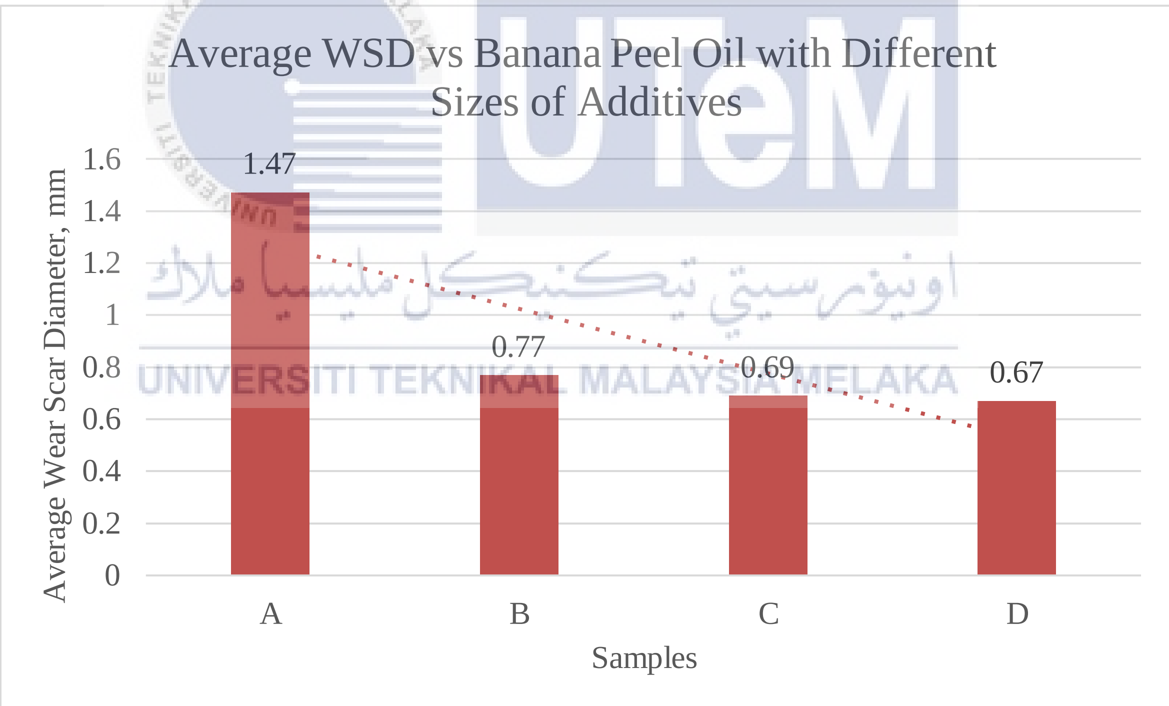

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Figure 4.3 Graph of Average WSD vs Banana Peel Oil with Different Sizes of Additives

4.2.1 Pre-Image of Wear Scar Diameter (WSD) of banana peel oil with different sizes of additive

After the four-ball test involving four distinct samples of banana peel oil with varied particle size additives, a wear scar emerged on the surface of the steel balls. Utilizing a portable mini electronic microscope connected to a computer, the wear scar left on the used steel ball underwent examination. The image of the wear was captured using dimension software, and its circumference was determined as depicted in Figure 4.26. In the four-ball test, the wear scar is assessed in a singular direction, with the average measurement of wear scar diameters formed on the ball calculated and documented. George Youssef claims that optical microscopes enlarge minute details on the samples using a set of glass lenses known as optics. Figure 4.26 presents the outcomes of four-ball tests conducted on banana peel oil with different particle size additives. The radius of ball sample A1 is 0.732 mm, sample A2 is 0.738 mm, and sample A3 is 0.741 mm. Compared to others sample oil, sample A has the largest radius of average wear scar diameter.

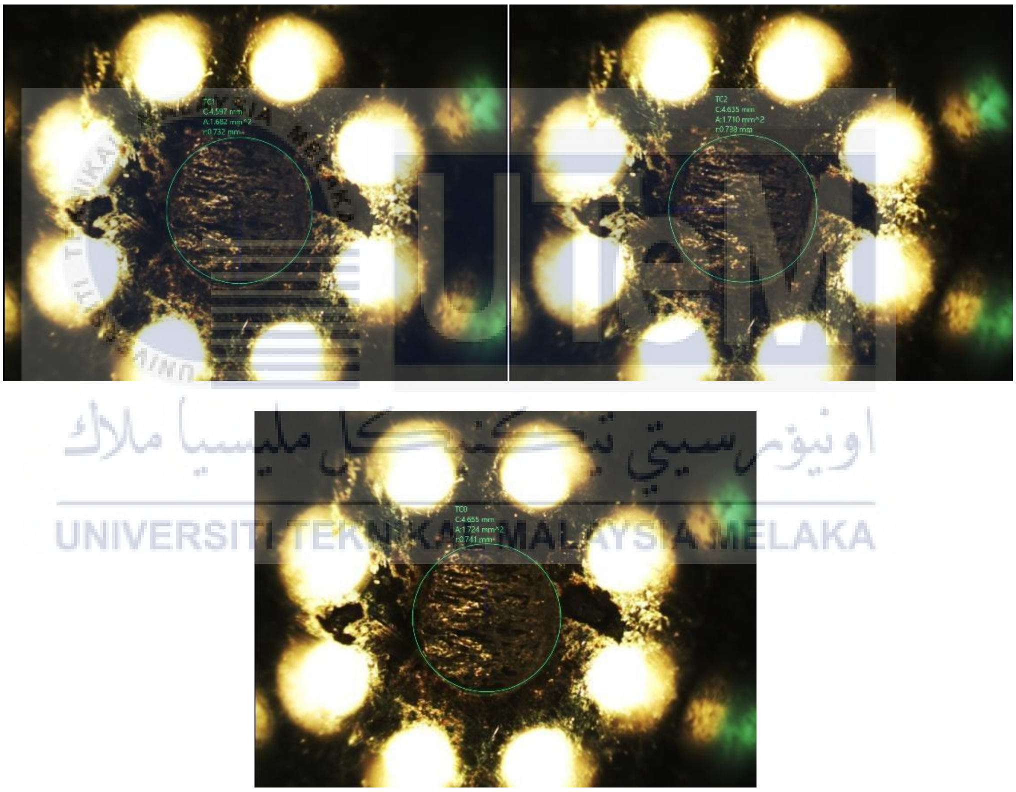

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Figure 4.4 a: Sample A1, b: Sample A2, c: Sample A3

The radius of ball sample B1 is 0.384 mm, sample B2 is 0.383 mm, and sample B3 is 0.381 mm. Compared to sample A, the radius of average wear scar diameter of sample B is smaller than sample A.

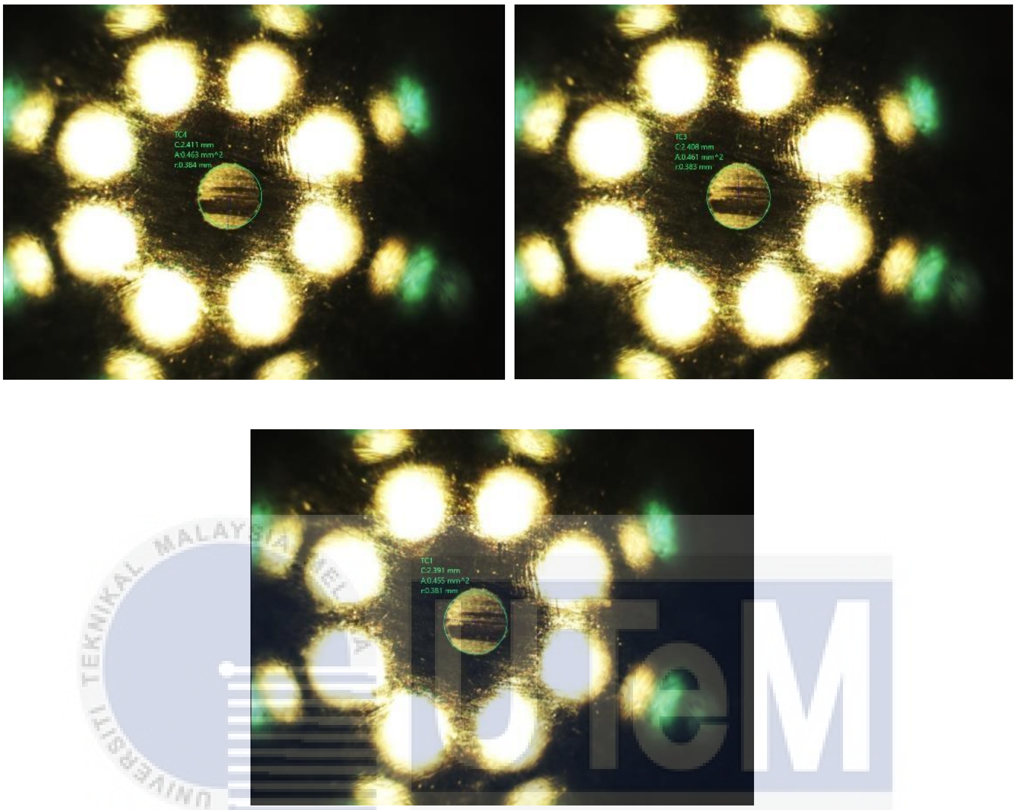

Figure 4.5 a: Sample B1, b: Sample B2, c: Sample B3

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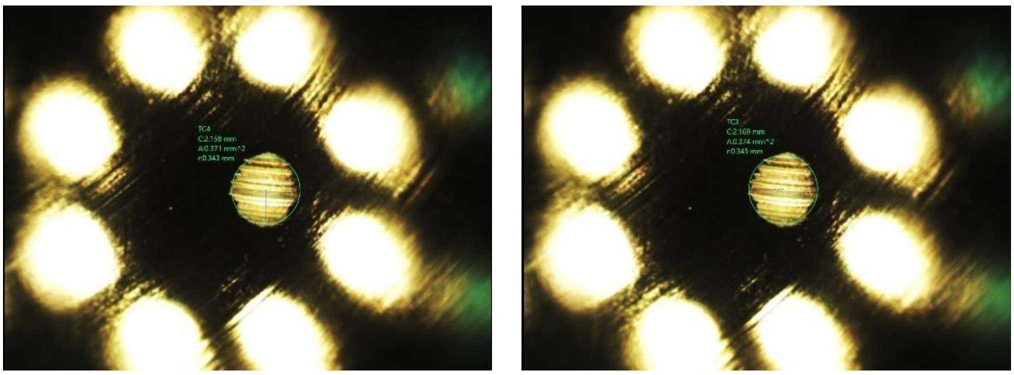
The radius of ball sample C1 is 0.343 mm, sample C2 is 0.345 mm, and sample C3 is 0.348 mm. Compared to sample B, the radius of average wear scar diameter of sample C is smaller than sample B.



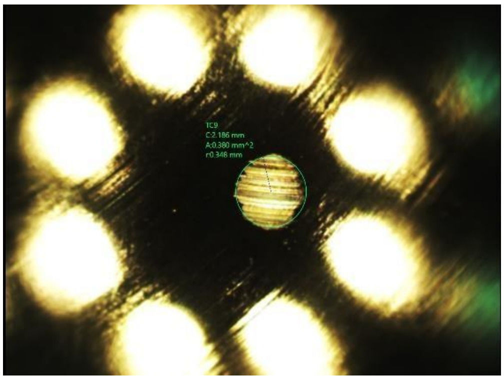


Figure 4.6 a: Sample C1, b: Sample C2, c: Sample C3

The radius of ball sample D1 is 0.334 mm, sample D2 is 0.333 mm, and sample D3 is 0.334 mm. Compared to others sample oil, sample D has the smallest radius of average wear scar diameter.

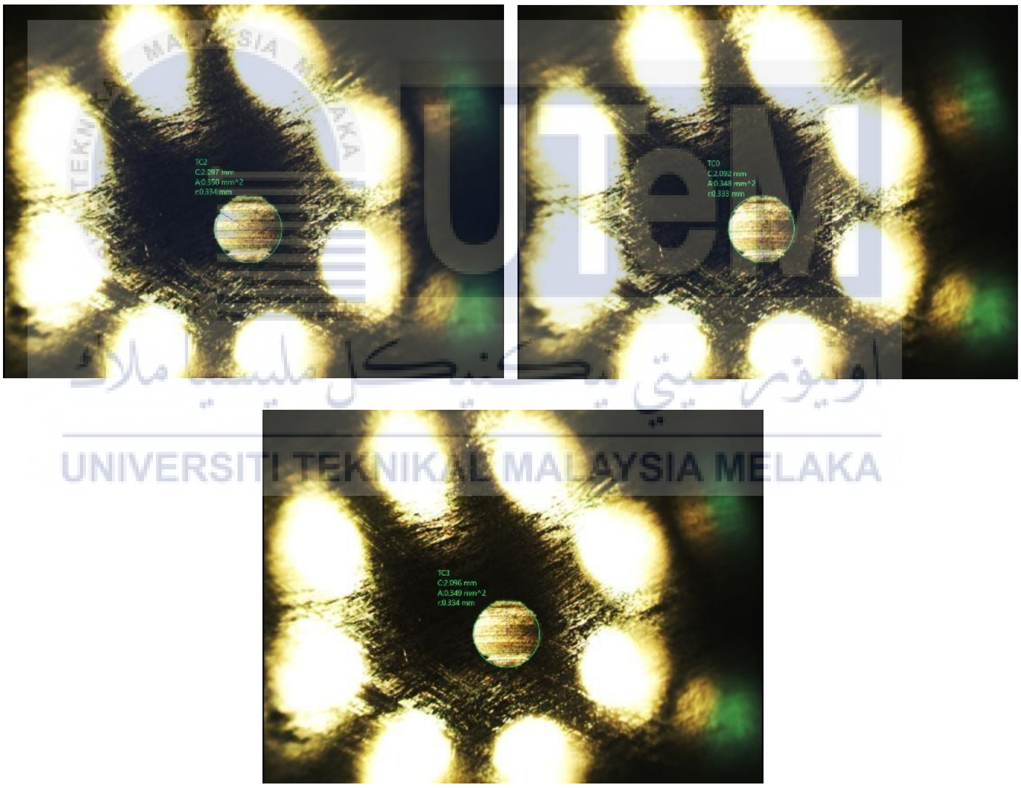


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Figure 4.7 a: Sample D1, b: Sample D2, c: Sample D3

4.3 Effect of additive on the Scanning Electron Microscope (SEM)

Scanning electron microscopy (SEM) was employed to analyze the morphologies of the surfaces of the worn steel balls. High-energy backscattered electrons and low-energy secondary electrons are stimulated to escape from the specimen's surface by the action of the electron beam (Bradbury et al., 2023). The SEM micrographs displayed in the figure below specifically depict the center of the worn scar on the disks. Through these micrographs, the anti-wear capability of the sample oil can be assessed. Figure 4.8 shows the SEM of balls of Sample A with 50X and 246X magnification. There is a lot of debris and scar on the surface of the steel ball, indicating that sample oil A does not have good lubrication properties. Due to increased friction, insufficient protection against wear, and compromised heat dissipation capabilities, these scars and debris appear on the steel ball surface, causing increased mechanical stress and surface damage.

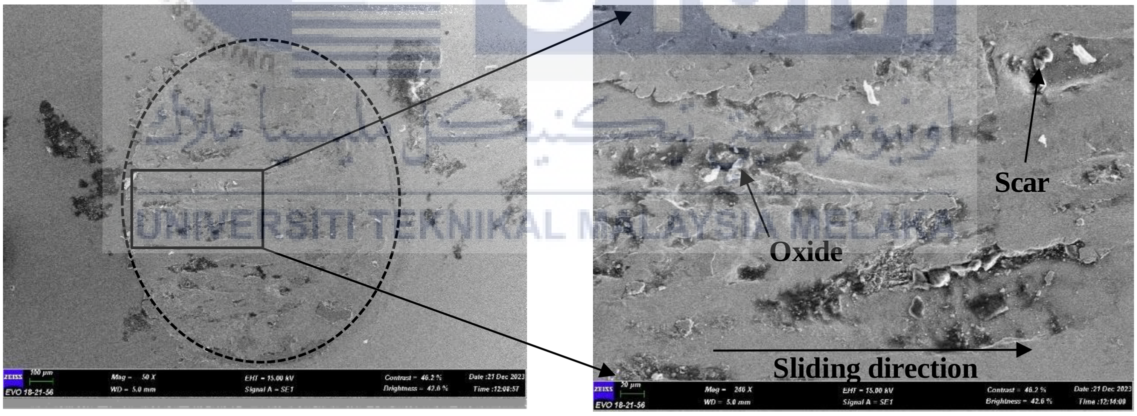

Figure 4.8 SEM of balls of Sample A

Figure 4.9 shows the SEM of balls of Sample B with 90X and 500X magnification. The surface of the steel ball has fewer debris and scars than the surface of the steel ball of sample A, which means that the lubrication performance of sample oil B is better than that of sample oil A. This is because the additive has started to perform, it can enhance the lubrication properties, reducing friction, preventing wear, and improving the oil's ability to withstand extreme conditions, thereby promoting smoother and more protective surface interactions.

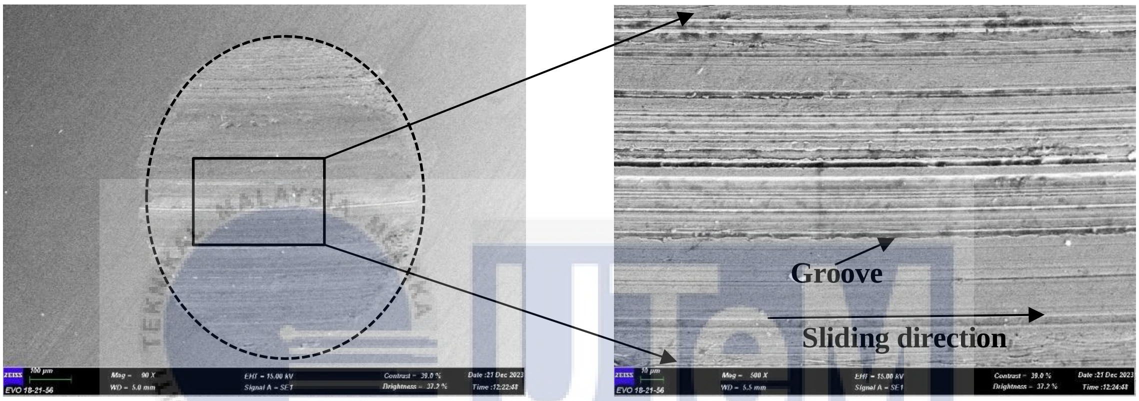

Figure 4.9 SEM of balls of Sample B

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Figure 4.10 shows the SEM of balls of Sample C with 90X and 500X magnification. Compared with the surface of the steel ball of sample B, the surface of the steel ball of sample C has less debris and scars. This is because nano size of additive is smaller than micro size, the smaller size of additive can more effectively penetrate microscopic gaps and irregularities in the contacting surfaces, leading to improved surface coverage, reduced friction, and enhanced lubrication properties, ultimately providing better protection against wear and minimizing damage.

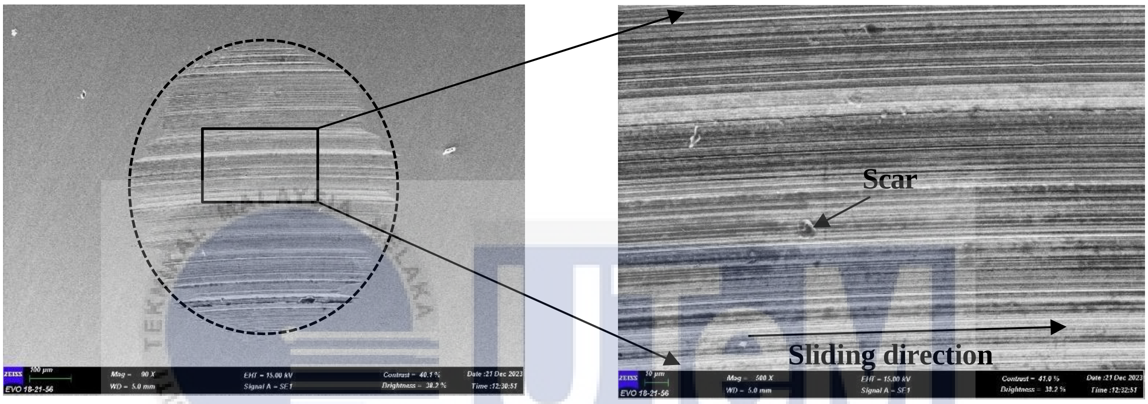

Figure 4.10 SEM of balls of Sample C

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Figure 4.11 shows the SEM of balls of Sample D with 90X and 500X magnification. Compared with the wear surfaces of other sample oils, the wear surface of sample oil D shows few signs of severe wear and is the smoothest and flattest, indicating that sample oil D has the best lubrication properties. Although the size of commercial additive is larger than that of nano and micro, the lubrication performance of commercial additive is better than that of nano and micro. This might be because larger-sized additives can provide robust film formation and better load-carrying capacity, especially in heavy-duty applications.

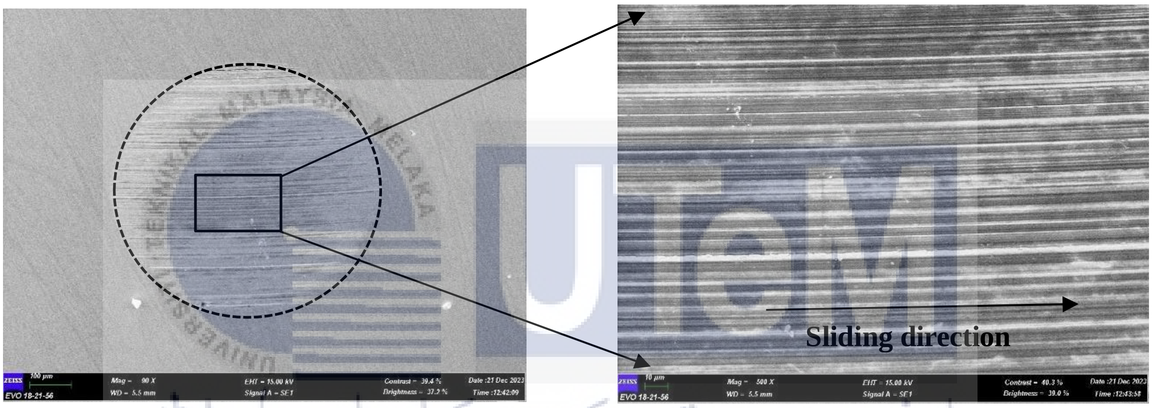

Figure 4.11 SEM of balls of Sample D

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CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this study, waste banana peel was extracted using Soxhlet Extraction Fat Analyzer SZF-06A machine to create a bio-based lubricant and then be added with three different sizes of Scallop-shell additives ($CaCO_3$), which are micro, nano, and commercial. The objective was to create new bio-based lubricants that can replace the mineral oils sourced from petroleum oil as a new, advanced, renewable bio-based lubricant for industrial applications that care for the environment and save costs. The extracted banana peel oil was mixed with 0.5 vol% of Scallop-Shell nanoparticles as an additive, and the samples were then homogenised by ultrasonication. A tribological test was conducted by using a four-ball tester according to the ASTM D-4172 where the Coefficient of Friction (CoF) and Wear Scar Diameter (WSD) were evaluated for each sample. Scanning Electron Microscope (SEM) was conducted to verify the wear mechanism occur. Samples with commercial Scallop-Shell additives were shown to have the best CoF (0.08385) and WSD (0.67mm) results in developing a new bio-lubricant. As a result, scallop-shell nanoparticles improved their physical properties, along with enhancing the good anti-wear and anti-friction characteristics of the lubricant mixtures compared to mineral oil.

In conclusion, addition of Scallop-shell additives into banana peel oil showed improvement in tribological properties by reducing the wear scar diameter (WSD) and coefficient of friction (CoF). The results showed that a little number of additives (0.5 vol%) can reduce the WSD and CoF as compared to pure banana peel oil.

5.2 Recommendation

As advice on how to make this study better, Further research and experimentation are needed to further understand the effects of scallop-shell additions and waste banana peel oils. More research is also required on the oil's anti-wear, anti-friction, flash point, viscosity index, and oxidation stability features model. In addition, it is necessary to explore more scale of the parameter value under the influence of multiple factors of banana peel oil characteristics such as vol%, time, load, and amplitude. Last but not least, in order to prevent bias and inaccuracy in the experiment, the four-ball test machine's repeatability and reproducibility must also be taken into account.

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REFERENCES

Abdullah, M. I. H. C., Othman, A., Abdullah, R., & Abdollah, M. F. (2019). Optimization on the nanoparticles stability in liquid phased condition by using Taguchi analysis. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, *61*(1), 129–139.

Acumen Research and Consulting. (2023, March 14). Bio-Based Lubricants Market Size Growing at 5.2% CAGR Set to Reach USD 4.9 Billion By 2032. GlobeNewswire News Room. https://www.globenewswire.com/en/news-release/2023/03/14/2626260/0/en/Bio-Based-Lubricants-Market-Size-Growing-at-5-2-CAGR-Set-to-Reach-USD-4-9-Billion-By-2032.html

Admin. (2023). Fluid Friction : Types of Friction With Detailed Explanation & Example | BYJU'S. BYJUS. https://byjus.com/physics/fluid-friction/

Amodu, O. S., Odunlami, M. O., Akintola, J. T., Ojumu, T. V., & Ayanda, O. S. (2022). Artificial neural network and response surface methodology for optimization of corrosion inhibition of mild steel in 1 M HCl by Musa paradisiaca peel extract. *Heliyon*, *8*(12), e11955. https://doi.org/10.1016/j.heliyon.2022.e11955

Arinbjarnar, Ú., Moghadam, M., & Nielsen, C. V. (2022). Application of Calcium Carbonate as Green Lubricant Additive in Sheet Metal Forming. *Key Engineering Materials*, *926 KEM*, 1133–1142. https://doi.org/10.4028/p-x87o62

Armylisas, N., Hassan, A., Hazirah, S., Fauzi, M., & Kian, Y. S. (2018). *Potential of Palm Oil Waste for Biolubricant*. 18–21.

Asikin-Mijan, N., Taufiq-Yap, Y. H., & Lee, H. (2015). Synthesis of clamshell derived Ca(OH)2 nano-particles via simple surfactant-hydration treatment. Chemical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Journal, 262, 1043–1051. https://doi.org/10.1016/j.cej.2014.10.069

Basiron, J., Fadzli, M., Abdollah, B., Ilman, M., & Abdullah, C. (2023). Tribology International Lubricant mechanisms of eco-friendly lubricant blended with mineral oil for steel-steel contact. 186(May).

Bradbury, S., Ford, B. J., & Joy, D. C. (2023, December 22). Scanning electron microscope (SEM) | Definition, Images, Uses, Advantages, & Facts. Encyclopedia Britannica. https://www.britannica.com/technology/scanning-electron-microscope

Cele, T. (2020). Preparation of Nanoparticles. In IntechOpen eBooks. https://doi.org/10.5772/intechopen.90771

Chew, S. C., & Ali, M. A. (2021). Recent advances in ultrasound technology applications of vegetable oil refining. *Trends in Food Science and Technology*, *116*(March), 468–479. https://doi.org/10.1016/j.tifs.2021.08.001

Clam. (2023, May 23). In Wikipedia. https://en.wikipedia.org/wiki/Clam

Contributors to Wikimedia projects. (2023, March 10). Coefficient of friction. Simple English Wikipedia, the Free Encyclopedia. https://simple.wikipedia.org/wiki/Coefficient_of_friction

Corporation, N. (2018, March 6). Lubricant Additives - a practical guide. Machinery Lubrication. https://www.machinerylubrication.com/Read/31107/oil-lubricant-additives

Five Things to Know about Lubricants Sustainability - Shell Lubricant Solutions | Shell Global. (n.d.). Shell Global. https://www.shell.com/business-customers/lubricants-for-business/sustainability/five-things-lubricants-sustainability.html

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Friction. (2023, April 24). In Wikipedia. https://en.wikipedia.org/wiki/Friction

Gupta, M., Kumar, R., Sharma, P., Adeeb, M., & Singh, R. C. (2019). Tribological Study of Banana PeelBroth of Musa Acuminate. Ijisrt.Com, 4(10), 506–513. https://ijisrt.com/assets/upload/submitted_files/1572259997.pdf

Her, S., Park, T., Zalnezhad, E., & Bae, S. (2021). Synthesis and characterization of cement clinker using recycled pulverized oyster and scallop shell as limestone substitutes. Journal of Cleaner Production, 278, 123987. https://doi.org/10.1016/j.jclepro.2020.123987

Hikal, W. M., Said-Al Ahl, H. A. H., Bratovcic, A., Tkachenko, K. G., Sharifi-Rad, J., Kačániová, M., Elhourri, M., & Atanassova, M. (2022). Banana Peels: A Waste Treasure for Human Being. *Evidence-Based Complementary and Alternative Medicine*, *2022*. https://doi.org/10.1155/2022/761645

Kennedy, J. (2020, January 29). Scallop Facts: Habitat, behavior, diet. ThoughtCo. https://www.thoughtco.com/facts-about-scallops-2291857

Khan, I., Saeed, K., & Khan, I. (2019). Nanoparticles: Properties, applications and toxicities. *Arabian Journal of Chemistry*, *12*(7), 908–931. https://doi.org/10.1016/j.arabjc.2017.05.011

Kibria, A. A., Kamrunnessa, Rahman, M. M., & Kar, A. (2019). Extraction and Evaluation of Phytochemicals from Banana Peels (Musa sapientum) and Banana Plants (Musa paradisiaca) . *Malaysian Journal of Halal Research, 2*(1), 22–26. https://doi.org/10.2478/mjhr-2019-0005

MacRae, D. (2022). Additives and Lubricating Oils: Working Together. Fluid Life. https://www.fluidlife.com/blog-additives-and-lubricating-oils/

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Musa × paradisiaca. (2023, June 14). In Wikipedia. https://en.wikipedia.org/wiki/Musa_%C3%97_paradisiaca

Pickles, M. (2017, August 11). Banana Anatomy. Monkey Pickles. https://monkeypickles.com/funny-nonsense/funny-articles/banana-anatomy/

Putra, N. R., Aziz, A. H. A., Faizal, A. N. M., & Che Yunus, M. A. (2022). Methods and Potential in Valorization of Banana Peels Waste by Various Extraction Processes: In Review. *Sustainability (Switzerland), 14*(17), 1–18. https://doi.org/10.3390/su141710571

Qu, T., Yao, X., Owens, G. K., Gao, L., & Zhang, H. (2022). A sustainable natural clam shell derived photocatalyst for the effective adsorption and photodegradation of organic dyes. Scientific Reports, 12(1). https://doi.org/10.1038/s41598-022-06981-3

Rajabi, H., Mosleh, M. H., Mandal, P., Lea-Langton, A., & Sedighi, M. (2020). Emissions of volatile organic compounds from crude oil processing – Global emission inventory and environmental release. Science of the Total Environment, 727, 138654. https://doi.org/10.1016/j.scitotenv.2020.138654

Rajesh, Y., Khan, N. M., Raziq Shaikh, A., Mane, V. S., Daware, G., & Dabhade, G. (2023). Investigation of geranium oil extraction performance by using soxhlet extraction. *Materials Today: Proceedings*, *72*, 2610–2617. https://doi.org/10.1016/j.matpr.2022.07.276

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Ravi, M., Murugesan, B., Jeyakumar, A., & Raparthi, K. (2021). A Review on Utilizing the Marine Biorefinery Waste in Construction Raw Materials to Reduce Land Pollution and Enhance Green Environment. *Advances in Materials Science*, *21*(3), 43–62. https://doi.org/10.2478/adms-2021-0017

Scallop. (2023, December 18). In Wikipedia. https://en.wikipedia.org/wiki/Scallop

Scanning electron microscope. (2023, June 2). In Wikipedia.
https://en.wikipedia.org/wiki/Scanning_electron_microscope

Syukriani, L., Febjislami, S., Lubis, D. S., Hidayati, R., Asben, A., Suliansyah, I., & Jamsari, J. (2021). Physicochemical characterization of peel, flesh and banana fruit cv. raja [Musa paradisiaca]. *IOP Conference Series: Earth and Environmental Science*, *741*(1). https://doi.org/10.1088/1755-1315/741/1/012006

The Banana Peel Trap. (n.d.). https://sciencefocus.ust.hk/banana

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

TriboNet. (n.d.). Four Ball Tester - About Tribology. https://www.tribonet.org/wiki/four-ball-tester/

Tsujimoto, A., Barkmeier, W. W., Fischer, N. G., Nojiri, K., Nagura, Y., Takamizawa, T., Latta, M. A., & Miazaki, M. (2018). Wear of resin composites: Current insights into underlying mechanisms, evaluation methods and influential factors. *Japanese Dental Science Review*, *54*(2), 76–87. https://doi.org/10.1016/j.jdsr.2017.11.002

Ultrasonics, H. (2023, December 4). Ultrasonic homogenizers. Hielscher Ultrasonics.
https://www.hielscher.com/homogenize_01.htm

What are Nanoparticles? Definition, Size, Uses and Properties. (n.d.).

https://www.twi-global.com/technical-knowledge/faqs/what-are-nanoparticles

Wikipedia contributors. (2023b). Scanning electron microscope. Wikipedia. https://en.wikipedia.org/wiki/Scanning_electron_microscope

Wypych, G. (2023). Coefficient of Friction. Handbook of Surface Improvement and Modification, June2020, 191–223. https://doi.org/10.1016/b978-1-77467-024-8.50015-0

Youssef, G. (2022). Characterization of polymers. In *Elsevier eBooks* (pp. 273–299). https://doi.org/10.1016/b978-0-12-821078-9.00016-8

Yun Yu, Y., Ilman Hakimi Chua Abdullah, M., Fadzli Bin Abdollah, M., & Teknologi Kejuruteraan Mekanikal, F. (2022). *Tribological investigation on vegetable oil enhance by hBN nanoparticles as future bio-based lubricant*. *August*, 246–247.

Zhao, J., Huang, Y., He, Y., & Shi, Y. (2021). Nanolubricant additives: A review. *Friction*, *9*(5), 891–917. https://doi.org/10.1007/s40544-020-0450-8

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