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PREPARATION AND CHARACTERIZATION OF NATURAL RUBBER COMPOUND USING TREATED AND UNTREATED WASTE COOKING OIL AS GREEN PROCESSING OILS

This report is submitted in accordance with requirement of the University Teknikal Malaysia Melaka (UTeM) for Bachelor Degree of Manufacturing Engineering (Hons.)

by

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DECLARATION

I hereby, declared this report entitled “Preparation and Characterization of Natural Rubber Compound using Treated and Untreated Waste Cooking Oil as Green Processing Oils” is the result of my own research except as cited in references.

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Date : 27 June 2022

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfilment of the requirement for Degree of Manufacturing Engineering (Hons). The member of the supervisory committee is as follow:

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ABSTRAK

Getah adalah bahan yang senang dijumpai dalam kehidupan seharian. Kebanyakanya, getah digunakan dalam pembuatan tayar, kasut dan juga komponen automotif. Sebatian getah terdiri daripada tiga komponen asas iaitu getah, minyak pemprosesan dan pengisi penguatan. Fungsi utama minyak pemprosesan adalah untuk menurunkan kelikatan dan meningkatan prestasi sebatian getah. Minyak aromatik seperti hidrokarbon aromatik polilik,sering digunakan dalam pembuatan produk getah kerana ia serasi dengan bahan tidak tepu. Walaubagaimanapun, minyak aromatik adalah berpontensi untuk menyebabkan kanser. Minyak pemprosesan aromatik boleh digantikan dengan alternatif yang lebih mesra alam. Oleh itu, sisa minyak makan yang telah dirawat, sisa minyak masak yang ditapis digunakan dalam penyelidikan minyak pemprosesan untuk getah sebatian. Kebimbangan tentang pengurusan sisa minyak masak telah timbul dan boleh memudaratkan alam sekitar. Dalam penyelidikan ini, sisa minyak makanan yang telah dirawat dan sisa minyak makan akan digunakan sebagai minyak pemprosesan untuk getah sebatian. Oleh itu, jumlah kuantiti minyak pemprosesan yang berbeza (0 phr, 5 phr, 10 phr, 15 phr, dan 20phr) telah digunakan untuk getah sebatian. Ciri-ciri penambahbaikan sifat sebatian getah yang mengunakan sisa minyak masak dan sisa minyak masak yang telah transesterifikasi adalah hampir sama. Keputusan dari uji kaji mekanikal dan fizikal sebatian getah tersebut menunjukkan perbezaan yang kecil di antara kedua-dua minyak pemprosesan ini. Kajian ini juga telah menunjukkan bahawa sisa minyak masak boleh digunakan sebagai minyak pemprosesan sejurus ditapis dari zarah yang tidak diingini. Kajian ini sangat penting kerana dapat meningkatkan kemungkinan untuk minyak pemprosesan yang baru dan kelebihan kepada produk daripada hasil sebatian getah.

ABSTRACT

Rubber is a material that is commonly encountered in daily life. Rubber is mostly used in tyre manufacturing, footwear, and automotive product. Rubber compounds are made up of three basic components: rubber, processing oils and reinforcing fillers. Processing oil is mainly used to lower the viscosity and improve the performance of rubber compounds. Aromatic oils, especially polycyclic aromatic hydrocarbons, are commonly utilized in the production of a variety of rubber compounds due to its compatibility with unsaturated materials. However, aromatic oils have the potential to cause cancer. These aromatic oils are frequently substituted with more environmentally friendly alternatives. Thus, this research discusses the possibility for chemically treated waste cooking oil and filtered waste cooking to be used as processing oils for the synthesis of rubber compounds. Waste management concerns related to used cooking oil have resulted in significant environmental implications. In this research, treated waste cooking oil, and waste cooking oil are utilized as processing oil for rubber compounds. Thus, different loadings of processing oils (0 phr, 5 phr, 10 phr, and 20 phr) were used in the rubber compound in this research. The rubber compound's cure characteristics show that the rubber compound with transesterification waste cooking oil and the waste cooking oil is almost similar. The result of mechanical and physical tests of natural rubber compounds treated with the waste cooking oil as the PO also shows a marginal difference between both of the processing oil. This study shows that the waste cooking oil can be used as processing oil after being filtered from the unwanted particle. This study is crucially significant since it will provide another possibility for oil processing that gives advantages to natural rubber compound products.

DEDICATION

To my beloved parents
William Anak Abang & Indai Pau Anak Urai,
my siblings
Olescynthya William & Samuel L. William,
my grandma
Poh Anak Meragan & Bahaga Anak Ugak,
my heroes
Abang Anak Entalai & Urai Anak Igoh.

I love you all. Thank you.

ACKNOWLEDGEMENT

"Glory be to the father, the son, and the holy spirit."

Better is the end of a journey in life than the beginning. I get hold of the grace of the Almighty God to begin and end all my final year projects in Jesus's name. Amen.

Deepest thanks to Ts. Dr. Jeefferie Bin Abd Razak, my respected supervisor, for his advice and commitment in supervising me through this whole research duration. His patience with my shortcomings was greatly appreciated. In addition, I also want to thank Sunrich Rubber Industry Sdn Bhd. and Puan Zallia for assisting me in conducting my PSM experiment. Furthermore, I'd want to express my gratitude to all of the assistant engineers who have lent me their expertise and knowledge in doing all of the necessary testing and laboratory tasks.

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LIST OF ABBREVIATIONS

ASTM	-	American Society for Testing and Materials
ISO	-	International Organization for Standardization
ACS	-	American Cancer Society
WCO	-	Waste Cooking Oil
TWCO	-	Treated Waste Cooking Oil
EO	-	Engine Oil
SEM	-	Scanning Electron Microscope
PAH	-	Polycyclic Aromatic Hydrocarbon
PO	-	Processing Oil
AO	-	Aromatic Oil
FTIR	-	Fourier- Transform Infared Spectroscopy
OH-	-	Hydroxyl
CHG	-	Greenhouse Gas
FFA	-	Free Fatty Acids
NR	-	Natural Rubber
VE	-	Vulcanizable Elastomers
VGC	-	Viscocity Gravity Constant
DIOP	-	Diisooctylphtlate
PHR	-	Parts per Hundred of Rubber
SMR	-	Standard Malaysian Rubber
HAF	-	High Abrasion Furnace (Carbon Black Filler)

LIST OF SYMBOLS

wt. % - Weight Percentage
vl. % - Volume Percentage
% - Percentage
°C - Degree Celsius
σ - Stress
kJ - Kilojoules
min - Minute
mg KOH/g - Milligrams of Potassium hydroxide per gram oil Sample
Pa - Pascal
Mpa - Mega Pascal
g/ml - Gram per Milliliter
dNm - Deci Newton Meter
tc90 - 90% Curing Time
ts2 - Scorch Time

CHAPTER 1

INTRODUCTION

The background of the study, problem statement, objectives, scope, the significance of the study, thesis organization, and overall summary were included in this chapter. A brief explanation on the experiment's background was also provided. In the background of the study write-up, brief statement on motivation of study, the novelty of the study and importance of the research were also included.

1.1 Research Background

In rubber compounding industry, processing oil is utilized to lubricate the rubber macromolecules and ease the mixing during compounding. They also helps in dispersing the filler and curatives. Thus, it was improved the natural and synthetic rubber compound's tensile strength and abrasion resistance. They are also responsible for increasing the physical qualities of natural and synthetic rubber compounds, such as elasticity, flex life, and lower temperature performance. The rubber compound has been developed for centuries to benefit humans for various importance technological application.

The rubber compound was mixture of between the natural rubber and other substances or known as curatives. The main reason for the mixing is to enhance the resulted strength of rubber vulcanization. As we know, raw natural rubber has limited usage due to its inferior properties. The rubber compound's numerous additional qualities might be improved when a specific substance is added. After the mixing, the rubber compound transforms into a more usable product (Ciesielski, 1999). As mentioned before, the rubber compound was mixed with multiple functional substances. This study has focused on the usage of processing oil for the preparation and characterization of natural rubber compounds.

Commercial processing oil for rubber industries are extracted from crude oil that are also used for many applications. Processing oils are composed of saturated hydrocarbons with linear and branching chains, whereas aromatic oil is composed of unsaturated aromatic hydrocarbons. Heteroatoms, such as oxygen, nitrogen, and sulfur, are commonly found in aromatic oil. In aromatic oils, the existence of heteroatoms affects their solubility by imparting polarity to the almost nonpolar hydrocarbon oil structure. Furthermore, the aromatic oil would induce devulcanisation and depolymerisation when exposed to higher temperatures. The heteroatoms have the potential to react with free radicals, reducing the effectiveness of peroxide crosslinking. It was anticipated that the crosslink concentration of the rubber macromolecules will be reduced as a result of this reaction. Since the density of compounded rubber are directly connected to the resulting compound physical and mechanical characteristics, thus, the mechanical and physical qualities would be significantly reduced as well (Li et al., 2016).

Highly aromatic oil is derived from petrochemical sector byproducts and has traditionally been widely utilised as rubber compounding extender oils in the rubber compounding industry. Their efficiency can be ascribed to their ability to work with most elastomer types. It was indeed possible to detect aromatic hydrocarbons in consumer items which manufactured from the recycled rubber, and these compounds are discharged into the environment. Their entry into the human body occurs by leaching (soil, groundwater, rivers), oral intake, contact exposure, and inhalation. As a result, skin contact or inhalation are considered the significant routes of exposure, with oral ingestion and environmental pollution being considered as the secondary hazards. The amount of Polycyclic Aromatic Hydrocarbon (PAHs) that have the potential to damage humans' health is comparable to the amount of pollution seen in large cities (Diekmann et al., 2019). Due to that, aromatic oil utilisation can be reduced or avoided. It can be replaced by using an alternative source of less harmful oils such as recycled oil from waste such as cooking oil or treated engine oil.

Waste cooking oil is among the major cause for water pollution. It was produced after and during the preparation of meals in food industry. The waste cooking oil has the potential of damaging and harmful to the environment. As a result, the production of biofuel of waste cooking oil is perhaps the most viable solution, and additional research into the characterisation of waste cooking oil is overwhelmingly required. The waste of cooking oil is comprised of the processed plant or animal fats.

Cooking oil is a glycerol ester composed of many forms of fatty acids that are only soluble in organic solvents, such as acetone. Waste is divided into two categories at room temperature which are fat and grease and liquid-shaped wastes. As a result of its insoluble nature in freshwater, it becomes a potential pollutant of the environment. Using waste cooking oil as an alternative fuel, biodiesel, or in a diesel engine has the beneficial potential. In order to manufacture the biodiesel-based product any source of fatty acids may be utilised, which means that if any plants or animals' lipid can be used as a substrate for the synthesis of biodiesel.

Biodiesel methyl-ester may be produced by using the transesterification process, in which the waste veggie oil or mammal fat interacts with alcohol in the presence of catalysts such as potassium hydroxide or sodium hydroxide. This is a more affordable and ecologically friendly alternative (Alias et al., 2018). When it comes to refining the waste oil, vacuum distillation as well as hydro-treatment are the favoured disposal alternatives in most nations. Combustion and incineration for energy recovery are other popular possibilities. However, due to the presence of undesired impurities in waste cooking oil, these disposal options are increasingly impracticable as environmental concerns as well as challenges which associated to costs (Lam et al., 2012).

The research aims of this study is to modify the waste cooking oil to be used as alternatives processing oil for the natural rubber compound. There are variety of bio-based resources which have great potential for replacing the petrochemical resources, including cooking oil, essential oil, palm oil, and a variety of other alternatives. In this research, the treated waste cooking oil and waste cooking oil to be used as processing oil for sustainable rubber compound. Moreover, this project has benefited in reducing the waste oil disposal problem caused by the waste oil as mentioned before and for the protection of the mother earth.

1.2 Problem Statement

Environmental problems have received more attention recently, resulting in high demand for new candidates of better alternative materials that are also environmentally friendly. The demand for rubber compound resources had increasing tremendously on the lateral side.

Various wastes are being used to substitute the commercially available resources. Wastes, or commonly known as by-products, resulting from industrial, agricultural, or households are generating no economic value, which must be appropriately disposed. Industrial wastes and by-products, whether solid or liquid-based, are abundantly available around the world. Environmental authorities in the majority of nations have enacted legislation and rules governing to the proper processing and disposal of waste oils. However, a significant quantity of this waste was illegally disposed of, posing severe environmental deterioration.

Each alteration made into rubber compound or procedure is likely to impact a broad range of the compound characteristics, whether uncured or cured, for the benefit or worse. As a result, every modification made to the rubber compound or production processes should be carefully studied prior to final application utilization. These modifications should be tested on a laboratory scale first to determine how they will impact the processability and cured physical and mechanical characteristics and the entire compound importance engineering properties.

Waste cooking oil is hazardous to the environment as well as to the health of those who exposed into it. According to the American Cancer Society (ACS), waste from frying oil is suspected to cause cancer due to the hazardous elements formed when the oil is oxidised from fried dishes. The majority of the by-products produced from the oxidation of cooking oil are toxic and carcinogenic. The disposal of waste cooking oil, on the other hand, will result in the obstruction of sewerage and drains. The dumping of waste cooking oil into the open water system will alter the oxygenation system and endanger the aquatic life because it will cover the water's surface and prevent oxygen from dissolving, so altering the processof oxygenation. Waste cooking oil has enormous potential for commercialisation since it may be utilised to manufacture goods such as biodiesel, which can help to minimise our reliance on natural resources. Waste cooking oil also has the potential to be recycled (Aliaset al., 2018).

Through the use of consumer items produced from reused rubber material has generated certain concerns about the discharge of hazardous chemical compounds into the environment. There is great concern about the prevalence of polycyclic aromatic hydrocarbons (PAHs) to the environment. These are complex mixes of organic materials whose chemical structure involves at least two or even more fused benzene rings, and in some cases, more than two. Polycyclic aromatic hydrocarbons have the potential to be carcinogenic, mutagenic, or reproductively toxic. Polycyclic aromatics have carcinogenic characteristics that are dependent to their molecular structures (Diekmann et al., 2019).

Cooking oil efficiency is comparable to that of aromatic as well as paraffinic oils. The results indicated that polymer compounds, including cooking oil has cured almost similar tothose cured by aromatic and paraffinic oils. It demonstrates that the cooking oil did not engage with the vulcanisation mechanism. Except, for rebound and resilience is different. The physical features of vulcanizates, including cooking oil, were nearly identical to those of vulcanizates. Cooking oil-containing vulcanizates possessed more resistance than aromatic and paraffinic oil-containing vulcanizates. This additional benefit was offered by cooking oil (Syamin et al., 2017).

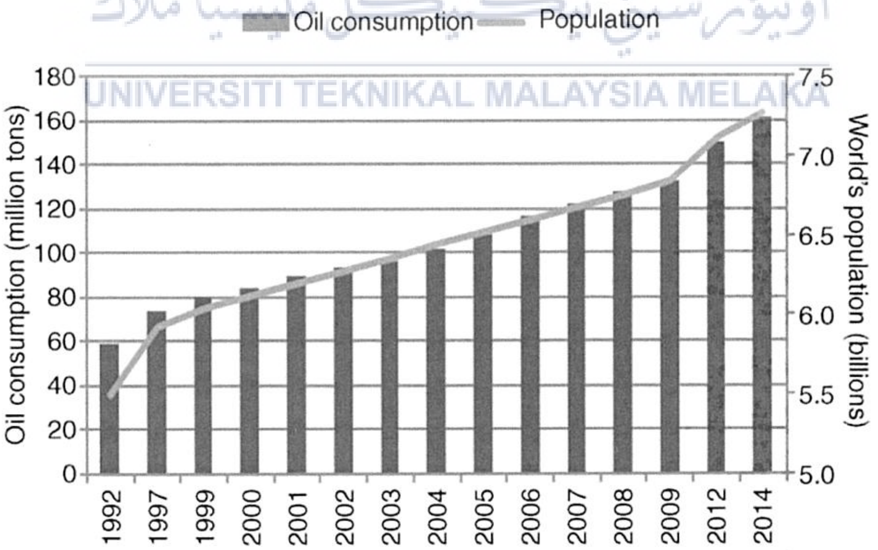


Figure 1.2: The consumption of Vegetable oil compared to the world population from 1992 until 2014 (Matthaus, 2016).

The above figure 1.2 shows the vegetable oil consumption as compared than the world pollution from year 1992 to 2014. The data shows that the consumption had increased from year to year. This is due to the vast production of vegetable oils to meet the global demand. Vegetable oil production and consumption has nearly quadrupled between the year of 1992and 2014 which is, from 59 Mt to 161 Mt. This growth in oil consumption has occurred concurrently with more or less linear increased in the world's population, from around 5.5 billion to more than 7 billion.

1.3 Objectives

The following are the research's objectives:

i. To evaluate the effects of loading variation for two different types of processing oil (untreated waste cooking oil and treated waste cooking oil) into the cure characteristic of natural rubber-based compounds by using the oscillating cure rheometer.

ii. To determine the effect of loading variation (0 phr, 5 phr, 10 phr, and 20 phr) of processing oil to the mechanical and physical properties of natural rubber-based compounds by using various related testing (tensile test, Shore-A hardness test, and density analysis).

iii. To relate the plasticiser effects of green processing oil addition with the fracture morphology of natural rubber-based compounds through the Scanning Electron Microscope (SEM) observation.

1.4 Scope of Study

The research scopes are as follow:

i. There is one type of processing oil that was utilized in this study which is the waste cooking oil. The processing oil that is tested are the untreated waste cooking oil and treated waste cooking oil.

ii. The weight percentages of the processing oil that was added to the natural rubber compound are 0 phr, 5 phr, 10 phr, and 20 phr. The 0 phr or non added sample was used as the control sample for the study.

iii. For testing the effect of processing oil to the natural rubber compound, both physical and mechanical testing were performed. The mechanical testing that was used is the tensile test and Shore-A hardness test. Meanwhile, the density testing has represented for the physical testing.

iv. For the cure characteristic, an oscillator cure rheometer test was performed to the entire uncured samples.

v. The frature morphology of the natural rubber compound was observed by using the Scanning Electron Microscope (SEM).

1.5 Significant of Study

Specifically, this research aims to evaluate and discover the possible usage of processing oil from the waste resources, including waste cooking oil and treated waste cooking oil.

This research could provide a better understanding on the effect to the rubber compound safter being loaded with processing oil. The mechanical properties and the physical properties were tested and evaluated. From the experimental result, the best candidate for processing oil has been chosen to be an alternative to the carcinogenic aromatic processing oil that are existingly used in common rubber industries. Next, the research is also to gain new knowledge for the alternative green prosessing oil such as tranesesterification waste cooking oil and waste cooking oil.

The scope of this research may be attributed to its own benefits. In this research, the use of processing oil is one of the most practical ways to utilise the disposed waste cooking oil in Malaysia. This has given a significant impact to the enviroment. This study also to searches the possibility of waste oils as potential source of alternative greenprocessing oil for natural rubber-based compounds preparation.

1.6 Thesis Organisation

Overall, this research was structured into five chapters, which are an introduction, literature review, methodology, results, and discussion, as well as conclusion and recommendations. This research was divided into two phases. The first phase of this research was on planning, and the second part is on the finding information. Thus, the first part has included the introduction, literature review, and methodology parts.

An introduction, which is the first chapter, has briefly explained the concept and background, the context, and the problem statement. Additionally, it includes the study's objectives, scope, and expected outcomes to be accomplished. Further, the opening chapter discusses the significance of study.

Following that is the second chapter, which provide the review on related past studies. This chapter is very critical to the study's success. This was served as the foundation of an overall investigation. In this chapter, discussions were made to the journals and articles with a similar scope of study. This chapter also discussed the steps and procedures involved in manufacturing of natural rubber processing oil. This chapter had additionally discussed the sustainable rubber compound, which has numerous benefits for humans and manufacturing. Besides that, the transesterification process, including its implementation and classification, was also be discussed in this chapter.

Chapter three provides explaination on the experimental methdologies. This chapter has mainly discussed the technique used for testing. Additionally, this chapter has discussed the preparation and equipments that were employed in this research's experiment. This chapter has also provided information to the physical and mechanical testing performed to the natural rubber compound samples.

This concludes the first section of this study by completing all these three chapters. The next chapter would be chapter four, which provided the results and related discussions. Finally,but certainly not least, the last chapter or chapter five has concluded the findings and results with several recommendations has been made for future research improvement.

1.7 Summary

After all, it was necessary to find the potential usage of waste cooking oil, and treated cooking oil into something beneficial for rubber industry. This is by developing a viable method for manufacturing of natural rubber-based compounds. The processing oil from waste cooking oil, and treated cooking oil can then be used as processing oil for natural rubber compounding purposes. The significance of this research had been discussed in detail in the subtopic of background information. Throughout this chapter, the problem statement has been adequately justified. For this study, three objectives have been set forth. The background and significance of the work have been fully explained.

CHAPTER 2

LITERATURE REVIEW

In this second chapter had explained the idea of producing natural rubber-based compound with addition of processing oil (PO) using several waste resources. Typically, the literature study explains the rubber compound, the properties and characteristics and the application of it. This chapter also covers related reviews on waste cooking oil as possible processing oil for rubber compound. Moreover, this section covers treated waste cooking oil that has been transesterified as sustainable alternative to synthetic processing oil. Last but not least, it also provide reviews for the methods that are used for testing and characterisation, as well as the resulted output from previous works done from other previous researchers.

2.1 Processing Oil for Rubber Compound

Rubber products are regularly used in human daily activities. Both synthetic and natural rubber are economically utilised for making a variety of products, ranging from rubber bands to toys to gigantic wheels for variety of vehicles, including planes and helicopters (Dewi, 2017). The applications of rubber compound in the manufacturing industry are tyres and construction related products.

Rubber compounds are composed of rubber, reinforcement fillers, process oils, and oil-based softeners. Other additives, such as stabilisers, antioxidants, and processing agents, are contained of lower concentrations than conventional additives. In rubber compounds, mineral oils with entirely different compositions are essential as softeners and extenders oils. Processing oil has been used for more than years (Öter et al., 2011).

Processing oil helps the rubber to enhance the elasticity and ease of processing. The processing oil are frequently used to reduce the viscosity and elasticity of pre-vulcanised materials, thereby increasing their ability to mix with other additives and flow more freely during the moulding process. The latter is by far the most utilised when it comes to well-known proçessing oil, such as paraffinic, aromatic, and naphthenic oils. This is because of its excellent compatibility with most elastomer types available in the market (Aline Zanchet et al., 2016).

Processing oil for rubber was utilised throughout a combination of rubber compounds. These processing oils assist in improving the distribution of fillers and the flow properties of the chemical as the compounding progressed further. Using a specified oil and other substance combination makes it possible to manufacture rubber goods of an acceptable grade (Singha et al., 2019). Two types of rubber processing oil are selected for this study which are the waste cooking oil and transesterification waste cooking oil. The type of rubber used is a natural rubber. The following section has provided further description review on the processing oils and natural rubber.

2.1.1 Existing types of Processing Oil

Paraffinic oil has been used as processing oil and becoming as an essential additive in the rubber industry for many years. The function of paraffinic oil is to reduce the viscosity, increase processability and improve the elastomeric quality (Li et al., 2016). Next, it also enhances the filler dispersion and moderating its glass temperature transition. Furthermore, it potentially decreased the toughness andtemperature resistance while also minimising expenses. For this research, two types of waste oil were be used which are waste cooking oil and transesterification waste cooking oil. However, many types of oil are used as the processing oil for the rubber compound. Following Table 2.1 are some examples of processing oil and its raw sources (Flanigan et al., 2013).

Table 2.1: Processing Oil Used for Rubber (Flanigan et al., 2013).

Oil Type	Raw Source
Vulcanized Vegetable Oil	Soybeans
Aromatic Oil	Crude Oil
Linseed Oil	Flax Seeds
Castor Oil	Castor Plant

Orange Oil	Orange Peel
Naphtenic Oil	Crude Oil
Soy Oil	Soybeans

Based on the Flanigan et al., (2013), the orange oil compound demonstrated behavior comparable to that of the aromatic controls. In the report, rolling resistance was observed in both linseed oil and vulcanized vegetable oil compounds, which the result showed promise. Most bio-oil molecules are in the vicinity of the trade-offline among both rolling resistance and lubricity (Boonmahitthisud et al., 2021). Next also stated that Castor oil was used in the compounds. However, the oil bloomed on the molded surface. The result of the castor oil was not recognized as a preferable replacement oil for paraffin oil. Depending on the efficiency and predictions and the physical characteristics of the oils, linseed oil and vulcanized vegetable oil were selected as two potential oil sources (A. Zanchet et al., 2019). The usage of these oils might be improved even more by either lowering the quantity of total processing oil used or increasing the amount of oil used.

2.1.2 Aromatic Processing Oil (PO)

As mentioned in the problem statement, aromatic oil is widely used in the rubber compound as a processing oil. But due to the polymer products that are produced by using the polycyclic aromatic hydrocarbons oil as processing oil is released toxic (Diekmann et al., 2019). This makes humankind concerned about the effect in the long term.

Due to their compatibility with unsaturated substances, aromatic oils are frequently used as processing oil to manufacture a variety of rubber compounds. Unfortunately, because aromatic oils have the potential to cause cancer, they are commonly substituted with more ecologically friendly alternatives (Saengdee et al., 2020).

So, based on ASTM D3184, the effects on natural rubber's curing and mechanical characteristics were studied by (Stelescu et al., 2018). The result of aromatic processing oil was shown to increase curing qualities comparable to those of aromatic oil (AO), which is commonly utilized in otherwise identical rubber compositions. Additionally, aromatic processing oil has been shown to increase the mechanical characteristics of natural rubber plasticizers. Based on Pakhathirathien et al. (2016), the optimized parameters for transesterification of stearyl aromatic processing oil were initially used in industry are to be a 1:1 molar ratio of alcohol to aromatic acid, a concentrated sulfuric acid catalyst concentration of 15% (by aromatic acid), and a reaction temperature of 85-95°C.

2.1.3 Sustainable Processing Oil

'Oil' is a standard term for viscous, typically liquids that are more or less viscous. A difference may be made between fatty, essential, mineral, and silicone oils based on their chemical characteristics. Fatty oils are liquid, semisolid, and solid compounds derived from plants and animals. Additionally, they are referred to as sweet oils. ASTM defines process oil as hydrocarbon oil generated from petroleum or even other sources that is employed as a solvent or processing oil (Pakhathirathienet al., 2016). The most extensively used processing oils for polymers and other rubber products have high aromatic content. The Table 2.1.3 below shows the common processing oil used for rubber compounds. The popularity is due to their compatibility with the majority of commonly used natural and artificial elastomers and their affordable cost.

Table 2.1.3: Aromatic Content (Dasgupta et al., 2007)

No	**Name of Oil**	**Clay Gel Analysis**			**Aromatics Content (%)**
		Polar (%)	Saturates (%)	Aromatics (%)	
1	Aromatic Oil	16	17	67	**36**
2	Paraffinic Oil	10	69	21	**9**
3	Naphthenic Oil	2	61	37	**12**
4	Low PCA oil	15	45	40	**18**
5	Rubber Seed	41	0	59	**30**
6	Neem	42	0	38	**4**
7	Dolma	40	0	60	**1**
8	Soybean	42	21	58	**1**
9	Alsi	38	0	62	**11**
10	Kurunj	42	0	58	**1**
11	Mustard	39	1	60	**1**
12	Ground Nut	42	0	58	**1**
13	Arandi, Castor	16	17	67	**1**

The world's population continues to grow, and the need for vegetable oils and fats for nutritional and technological uses is growing. The difficulties for a sustainable oil processing sector are becoming more severe. Sustainable oil processing entails utilizing available resources without depleting them further. Matthäus, (2016) state that the stricter regulatory requirements have resulted in more significant attempts by the oil processing sector. Next, the properties of the processing oil are also important. This is because different types of processing will have different effects on the rubber compound. The properties of processing oil is discussed in the next topic.

2.2 Processing Oils used in the Research

The main application of processing oil is to reduce the viscosity and enhance the performance of rubber compounds. In this part, the information pertaining about the processing oil for the natural rubber compound are revived.

2.2.1 Type of Processing Oil (PO)

As prior mentioned, the recycled oils that used in this study are the waste cooking oil, and transesterification waste cooking oil. For the treated waste cooking oil, the waste cooking oil has undergone the transesterification process. Following section had discussed the type of recycled oil that used in this study.

2.2.1.1 Waste Cooking Oil (WCO)

Waste cooking oil is the waste of frying dishes in cooking oil that comprises processed plant or animal fats (Alias et al., 2018). Cooking oil is a glycerol ester composed of various essential fatty acids that are soluble exclusively in organic solvents. Cooking oil was originally derived from plant-based lipids such as coconut oil, palm oil, or animal-based lipids such as butter. Waste cooking oil has various characteristics depending on the source of the waste.

Waste cooking oil has been one of the forms of water pollution that may be influenced by multiple circumstances. It was produced during the preparation of meals such as café. Sadly, the waste cooking oil has the potential to be detrimental to the environment (Dong et al., 2018).

2.2.1.2 Treated Waste Cooking Oil (TWCO)

The treated waste cooking oil is expected to positively influence the environment through the recycling efforts by rubber manufacturers. Thus, its effort is one of several possibilities for assisting recycling companies that convert trash to money and riches to waste.Simultaneously, this one treated waste cooking oil can be implemented to solve the issue of cooking oil disposal by limiting the usage of waste resources and therefore preserving the environment's balance.

Treated waste cooking oil has successfully utilized as a raw material in synthesizing green processing oil produced by the transesterification process.Waste cooking oil was selected as raw material in this study because it comprises of triglyceride structure that may be chemically changed. The presence of hydroxyl groups in the treated waste cooking oil is determined by using Fourier-Transform Infrared spectroscopy, as FTIR spectroscopy is capable of scanning materials for the availability of functional groups. The presence of hydroxyl group (OH-) peaks in the infrared spectrum at wave number of (3441cm^{-1}) is validated and established in order to make a WCO-based processing oil. The objective of treating the waste cooking oil is to increase the efficiency of the waste cooking oil as prosesing oil for rubber compounds(Alkahlani, 2021).

2.2.1.3 Engine Oil

Alternative energy sources have indeed been researched in recent years to replace fossil fuels due to the depletion of this supply. This had resulted the rising demands and expenses. The utilization of waste engine oil for generation of diesel appears to be a viable method of creating alternative fuels. Waste oil is produced from variety of industries, including manufacturing, transportation, airlines, and maritime (Maceiras et al., 2017). According to Maceiras et al., (2017) each year that 380 million gallons of spent motor oil are expected to be recycled each year.

Worldwide, it was stated that about 45 percent of spent motor oil is recovered, while the remaining 55 percent is discarded or disposed to in the environment. Additionally, 40% of all reused oil is illegally disposed. Used engine oil is an excellent candidate for recycled types processing oil.

This study had justified the use of waste motor oil as a replacement for hydrocarbon-based processing oil. The research on utilizing waste engine oil as processing oil is still limited. The result of using waste engine oil as processing oil for rubber compound in this study will be compared with the use of waste cooking oil. However, due to the time limitation, the scope has been revised for not using the waste engine oil but just comparing the performance of waste cooking oil and treated waste cooking oil for posible processing oils of natural rubber compounds.

2.2.2 Collection and Refining of each Processing Oil

Prado et al., (2021) has stated that in year 2018, the global food supply chain that generated approximately about 13.6 Gt of CO2-eq year-1, accounting for approximately 26% of total anthropogenic greenhouse gas (GHG) emissions. Food processing has contributed for 4% (544 Mt) of this total, highlighting the need of reducing GHG emissions in this sector. According to year 2019 study, an investment group managing $6.5 trillion urged of the world's major fast-food restaurant businesses to cut greenhouse gas emissions but also for the water use. The majority of big fast-food chains has pledged to reduce the GHG emissions. One of the famous fast food supply chains has set a goal of reducing GHG emissions out of its restaurants and offices by 36% by 2030, as well as other fast-food companies have either set GHG emission reduction targets or are planning to do so in the near future (Golden, 2019).

In the cycle of year 2015 Mielke, (2017) also had stated that the vegetable oils were the primary feedstock for biodiesel manufacturing. In that year, about 8.7 million tonnes of palm oil were utilised, accounting for 29.2 percent of all substrates used in the manufacturing of biodiesel (including HVO). Additionally, about 7.7 million tonnes of soy oil (28.5%) and 7.0 million tonnes of rapeseed oil (23.6%) were utilised as feedstock. Furthermore, paraffin is a significant feedstock for the manufacturing of biodiesel, accounting for 2.26 million tonnes in 2015. However, special emphasis is placed on the four primary oils: soy oil, palm oil, rapeseed oil, and as well as the sunflower oil.

Over the last two decades, global consumption of 17 fats and oils has more than quadrupled, from 92.9 million tonnes in 1995 reaching 204.3 million tonnes in 2015. By far the majority of increase over the last two decades has been for edible uses, particularly in Asia and Africa, owing to population expansion and increased consumption per person due to changing diets as well as rising income levels. Since 2004, annual increased in overall consumption of all oils and fats have accelerated, owing in part to increased biodiesel production (Mielke, 2017).

2.2.3 Properties of Processing Oil

The waste cooking oil is a triglyceride composed of various fatty acids. Around 94% to 96% of overall mass, the waste cooking oil is triglyceride oil. Furthermore, saturated fatty acids of waste cooking oil do not contain any double bonds. In comparison, the unsaturated fatty acids have one or maybe more double bonds. Oil processing produces a variety of properties, including lower viscosity and good rubber compatibility. It was determined that the processing oils are compatible with rubber and can improve their processing capabilities. Based on Table 2.2.3, it showed the cure characteristic of each oil according to the Flanigan et al (2013). The cure time of rubber compound loading with palm oil and soybean as processing oil is almost similar to the rubber compound without adding processing oil. Meanwhile, the rubber compound added with coconut oil as processing oil show the cure time is increase around 9.23%.

Table 2.2.3: Properties of NR compound with the types of PO (Flanigan et al., 2013)

Types of PO in the NR compound	**Mixing energy [kJ]**	**Mooney Viscosity [ML (1+4), 100]**	**Scorch Time [min]**	**Cure Time [min]**	**MH-ML**
Without Oil	775	41.5	2.59	10.4	14.76
Coconut Oil	626	34.4	3.31	11.36	9.85
Palm Oil	574	30.0	3.32	10.09	8.95
Soybean Oil	557	25.2	3.37	10.02	8.71

2.2.4 Application of the Processing Oil

Cooking oil is not responsive under polyurethane chemistry conditions because it lacks hydroxyl groups. As a result, it must be designed and synthesized with hydroxyl groups to be utilised as a greener raw material for polyurethane products and other application such as plasticizers, stabilizers, and lubricant additives. Due to their availability and low cost, palm oil derivatives appears to be an environmentally beneficial source for bio-based goods. Intharapat et al., (2020) has stated that the findings indicate that Jatropha seed oil, which was used as the processing oil, had promoted similar rubber processability to paraffinic oil. The application of naphthenic oils added the benefit of a shorter cure scorch time. The alteration of oil using peroxyl acid, in particular, results in an epoxidised oil that may be utilised as a pocessing oil in rubber. Epoxide groups in oil can increase carbon black's polar–polar interaction, allowing it to serve as a coupling agent and improving the high thermal stability of carbon black-filled rubber (NR) compounds (Moresco et al., 2020).

Edible vegetable oils, also used as processing oil, are among the most actively researched plasticiser options because they are sourced from renewable sources, making them widely accessible and biodegradable. When added to rubber, they work as both a plasticiser and heat stabilizer (Suzuki et al., 2018).

2.3 Transesterification

The term "transesterification" refers to the direct transformation of triacylglycerol lipids. This is due to alcohols added into alkyl esters without first separating the free fatty acids (FFA) (Yuen May, 2004). This is to form the glycerol as well as the ester (Park et al., 2015). The process of transesterification was conducted in three consecutive steps. The step one is to convert the triglyceride to diglyceride. Followed by diglyceride converted into monoglyceride and finally to glyceride. These each step of the process is important to produce the methyl esters. Hingu et al., (2010) stated that the vigorous mixing is necessary to improve the contact surface between the two phases and get considerable reaction rates for ester formation.

2.3.1 Transesterification of Waste Cooking Oil (WCO)

Milano et al., (2018) has claimed that the microwave-assisted transesterification is an excellent method for increasing the output and producing high-quality methyl ester from the waste cooking oil. There are few importance properties of the waste cooking oil. The waste cooking oil is composed of two types of acid which are the lioleic acid and oleic acid. These two acid types are unsaturated fatty acids consists in the waste cooking oil (Hingu et al., 2010). Less than 3% of free fatty acid content are available inside the waste cooking oil. The following Table 2.3.1 is for the properties and composition of waste cooking oil. Next, the effect of transesterification was discussed in the following section.

Table 2.3.1: Properties and Composition of Waste Cooking Oil (Hingu et al., 2010)

Properties	**Waste Cooking Oil**
Acid value (mg KOH/g oil)	2.805
Density (kg/m3)	925
Linoleic Acid (%)	53.4
Oleic Acid (%)	35.34
Stearic Acid (%)	2.16
Palmitic acid (%)	9.08
Saponification Value (mg KOH/g oil)	208

2.3.2 Transecterification Effects

All steps of the transesterification process are reversible. Adding enough alcohol can affect the equilibrium, towards reaction completion. The fatty acids can be produced in acid catalysed transesterification. It was accomplished by adding it with the water in the reaction mixture (Yuen May, 2004). For acid transesterification, process parameters such as the methanol to oil ratio, the sulfuric acid concentration, and the irradiation period were improved. This transesterification process reduces the waste cooking oil's FFA value from 8.8 to 1.1 percent. Further improvement of the alkaline transesterification process parameters resulted in a biodiesel yield of up to 90% (Vishal et al., 2020).

Next, transesterification also has a slower response time and of higher operating heat when using the alkaline catalysts. Just after the free fatty acid content of the oils is decreased towards less than 1%, further transesterification phase utilizing an alkaline catalyst is undertaken. Direct transesterification is a process when the biomass is transesterified directly by using alcohol and a catalyst in a single reactor (Park et al., 2015).

Last, the transesterification also can be affected by the stirring speed of the processing oil. Yuen May, (2004) has stated that the temperature must be maintained and controlled in the water bath for better transesterification results.

2.4 Rubber Compound

Compounding is the process of adding various substances to a rubber matrix to enhance the functional characteristics of rubber matrix. The process starts with the raw natural rubber and turns it into the desired polymer product (Zheng et al., 2018). The natural rubber has a very restricted application due to its inability to retain its form after being cured.

The top priorities of rubber compounding are to fulfill the end qualities of the rubber compound. It was also to meet advanced processing requirements of manufacturing for rubber products. The balance between the characteristics and the rubber's cost also needs to be maintained. Achieving an appropriate mixture of elastomeric matrix's compounded components was essential for successful compounding and plasticization. Hardness, tensile characteristics, tensile stress, set characteristics, resistance to abrasion, and flex qualities are some of the properties that must be set before compounding the rubber (Sisanth et al., 2017).

2.4.1 Natural Rubber Compound

Rubber, in particular natural rubber, is among the essential elastomers. The natural rubber compound is widely used in manufacturing, innovation, and engineering fields. It is due to its outstanding and unique material properties. A prominent purpose rubber, natural rubber (NR), continues to be a substantial general-purpose rubber due to its exceptional cost-effectiveness ratio. It is particularly significant in the applications of car tires, where the dynamic characteristics of natural rubber are essential. The natural rubber compound also makes it practical and unique material in specific applications such as tires, mounting, plastic tables, and seals (Rachtanapun et al., 2021).

The natural rubber compound is also used in the production of synthetic rubber. It has long been standard practice to reinforce rubbers using commercially available fillers to achieve the characteristics that necessary for the intended uses. Due to the high need for better material characteristics, many researchs on submicron reinforcing fillers and processing oil have been conducted in recent years. (Ismail etal., 2011).

2.4.2 Natural Rubber Composition

Based on Sisanth et al., (2017), it was possible to obtain natural rubber from the rubber tree, Hevea brasiliensis, which is the most widely used source of natural rubber in the world. The aqueous colloidal dispersal of rubber particles, known as natural rubber latex, is produced by tapping procedure. Cis-1,4 polyisoprene units are found in natural rubber produced by the biosynthetic route. It includes of 30/40 weight percent dry rubber, 3.5 weight percent of non rubber component, and the remainder water. The rubber particles are spherical in form and have a particle size of 0.02 microns, a specific gravity of 0.92, and a pH of 7. Fresh latex coagulates spontaneously after a few hours, but this can be avoided by applying anticoagulants such as ammonia, formalin, or other anticoagulants to the latex before used. Different types of natural rubber are employed, including dry rubber form and liquid rubber form. The following Table 2.4.2 is the composition for natural rubber.

Table 2.4.2: Composition of Natural Rubber (Matador, 2007)

Substance	**Content, %**
Rubber	30 – 40
Resins	1.5 – 3.0
Protiens	1.0 – 1.5
Minerals	0.7 – 0.9
Water	55 – 60
Carbohydrates	0.8 – 0.1

The natural rubber is form from the rubber particles distributed in water which also know as colloid system. The size of the particle is changing to 3μm from 0.05 μm. Additionally, NR latex contains minor amounts of proteins, resinous materials including lipids, hydrocarbons, and mineral components. A portion of these non-rubbery substances, primarily proteins and lipids, are surrounded by a rubbery particle surface, which provides them a negative charge, ensuring the latex's stability. Fresh NR latex has a specific weight of 0.96 – 0.98 g x cm^{-3} while the pH range is around 6.5 – 7.0. It coagulates when it is suspended in the air, and as a result, it must be stabilised (Matador, 2007).

The analysis showed after loading with the processing oil, the molecular mass among crosslinks of the vulcanizates rose. The processing oil implies that the vulcanizates' crosslinking density reduced (Karak, 2012). The rubber added with the processing oil would induce devulcanisation and depolymerization. This decreases the density of the physical crosslinks generated by the entanglements (Li et al., 2016).

2.4.3 Vulvanization of Natural Rubber Compounds

Vulcanization is a critical step in the majority of rubber technologies. Vulcanization is the process by which a rubber compound transforms into the rubber product. This is accomplished through few procedures and steps to change the chemical and physical changes according to the needs (Ismail et al., 2001). Following is the Figure 2.4.3 of the rubber that have been vulcanized.

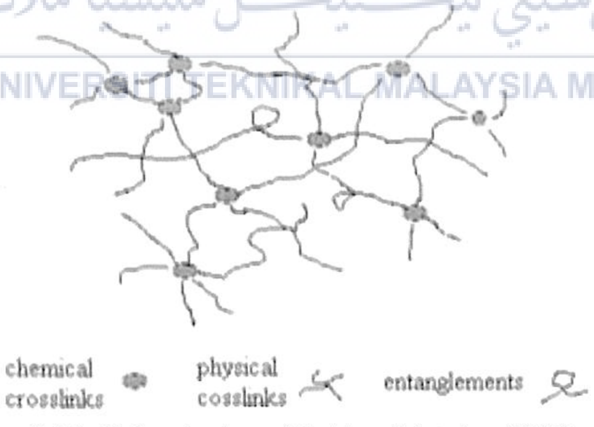


Figure 2.4.3: Vulcanization of Rubber (Matador, 2007)

Sulfur is used as the conventional cure for rubber. Sulfur-based vulcanization of rubbers is a very slow and unreliable process. The chemical reaction between sulfur and rubber hydrocarbons occurs primarily at the C = C (double bonds). Each crosslink requires between 40 and 55 sulphur atoms. The process takes approximately six hours at a temperature of 140°C to complete, which would be impractical by any manufacturing standard. The vulcanizates produced in this manner are extremely susceptible to oxidative degradation and lack the mechanical properties required for rubber product applications (Kalkornsurapranee et al., 2017). The element of vulcanizate network are physical bonds like hydrogen bond, polar or scattered. It was generated at preparation or processing of rubber compound. The rest of substances participating in rubber compound are in original or altered form chemically bonded, dispersed as well as soluble.

Materials that are distinctive and versatile in that they may be reversibly deformed under influence of an external deformation forces are known as vulcanizable elastomers (VE). Low deformation stresses can result in deformation percentages ranging from a few hundred to thousands of percent due to the structure as well as molecular mass of the rubber as well as the external conditions under which the rubber is deformed (Kruželák et al., 2017).

2.5 Properties of Rubber Compound

Standard rubber compound compositions have ten or more components. It used to improve physical characteristics, impact vulcanization, avoid long-term degradation, and increase processability (Mohamed et al., 2017).

Rubber is a group of materials with a large molecular weight. The average weight of the rubber is not constant. It is usually different depending on the process to compounding the rubber. The viscosity in rubber solutions is determined by their concentration, the composition of the solvent, and the previous treatment used to lower the relative molecular mass. Certain rubber qualities vary significantly as a function of temperature (Franta, 1989; Ismail et al., 2001). Thus, from a technical perspective, the following characteristics of rubber are critical and applied:

1. Rubber compounds have excellent elasticity.
2. Rubber can also absorb energy during deformation.
3. Rubber has resistance to repeated deformation cycles.
4. Rubber is also excellent in resistance, resistance to wear, and hardness.
5. Rubber is waterproof and impermeable to gas.
6. Rubber is also resistant to resistance.

7. Have good insulator to electrical
8. Some products made from rubber can be used for a period.
9. Rubber is not expensive like other products.

Based on Surya et al., (2017) in order to get the characteristics required for certain applications, it is common practise to reinforce rubbers using readily accessible commercial fillers. Because of the increasing need for improving the material characteristics in current history, numerous studies on nano-sized reinforcing fillers have been conducted in the past several years.

2.5.1 Mechanical Properties of Rubber Compound

The polymer has low tensile strength and can withstand deformations of up to one thousand times of its original size. Following such deformation, it returns to its original size in a short period. Rubber may be formed into a variety of forms and attached to metal inserts or mounting plates, among other things. It may be combined with other substances to provide a wide range of characteristics (Ronald, 2016).

Rubber materials come in various mechanical characteristics to suit a variety of final applications. Mechanical analysis is the process of determining the physical strength of a material, which includes its tensile strength, hardness, tensile modulus, tear strength, and elongation at break. Tensile strength defined as the force required to break a material when it is pulled or stretched; this is the force needed to break a substance when it is stretched (Mente et al., 2016).

Based on Ronald, (2016), the resistant to indentation is described as the hardness of a material. Essentially, the durometer is a device that measures the amount of rubber that is penetrated by a metal sphere that has been stressed. According to ASTM test protocols, hardness values in rubber, depending on the material. For this reason, due to the viscoelastic characteristic of rubber, a durometer reading achieves its highest value as soon as the metal sphere penetrates the material to its maximum depth, and then gradually drops over the next 5-15 seconds. Although they are extremely susceptible to operator mistakes, hand-held spring-loaded durometers are widely used. Instruments that are dead-weight-loaded on a bench decrease the amount of error to a bare minimum.

Tensile modulus is a property of a material that shows its resistance to deformation under pressure; it is inversely proportional to the material's stiffness (Sovtić et al., 2020). Elongation upon break refers to a material's ability to stretch multiple times its initial length; this is a critical property of rubber. Composites' modular, tensile, and tear strengths were optimized at moderate or even lower filler loadings and were further improved by including a bonding agent (Ku et al., 2011). Tensile strength is by far the most often utilized indication of plasticization-induced changes.

2.5.2 Physical Properties of Rubber Compound

Due to the numerous unique properties of rubbers, tests designed for other solid materials are rarely applicable to them. Due to rubbers' extreme deformability and low modulus, their test equipment must be accurate at displacements and forces greater than those required for the majority of engineering materials. Rubber and rubber products are evaluated for their ability to perform the unique functions enabled by their viscoelastic properties both initially and over time. In summary, physical testing is always conducted for cost-effectiveness (Rodgers et al, 2005).

According to the physical characteristics of a rubber compound, elastomericmaterials can be transformed. On the other hand, natural rubber is a fascinating material because of its ideal physical qualities. Its high mechanical strength, minimal heat build-up, shock resistance, and outstanding durability (Indrajati et al, 2017).

The mass, density, and dimensions are included in the common physical properties of the material. Density is typical to use in the industry to check the rubber compound error. The density is the mass per unit volume of the specimen. The relative density is the specimen's mass compared to the mass of the water. The measurement technique frequently involves determining the relative density of water. The water is assumed to have a density of 1Mg/m (Dick, 2003). Additionally, the determination is frequently accomplished by observing gravitational forces.

2.6 Plasticiser Effect of Processing Oil for Natural Rubber Compound

Plasticizers are active additives added to polymers to increase their flexibility, plasticity, ease of processing, and elongation. There are two forms of plasticizer which are petroleum-based and ester plasticizer. The petroleum-based plasticizer is classified as paraffinic, aromatic, and naphthenic. Each type has a different point of aniline and viscocity gravity constant (VGC) (Sisanth et al., 2017). The following Table 2.6 summarized the VGC as well as theaniline point of the petroleum-based plasticizer.

Table 2.6: The content of VGC and Aniline point of petroleum-based Processing Oil (Maslowski et al., 2017)

Petroleum-based Processing Oil	**VGC**
Paraffinic Oil	0.78 to 0.82
Aromatic Oil	0.95 to 1.00
Naphthenic Oil	0.85 to 0.9

The second type is the ester plasticizer, it always used in a rubber compound such as crumb rubber. A few types of ester plasticizer are diisooctylphtlate (DIOP), dibutyl sebacate, and triallyl phosphate. Plasticizers reduce the polymer's glass transition temperature, the most common rationale. It also makes the rubber compound more flexible on the polymer structure (Masłowski et al., 2018). This can typically be assessed by a drop in the glass transition temperature. Enhanced elongation and reduced tensile are typical results of a decrease in the glass transition temperature caused by the addition of plasticizers. Specific effects are also observed in some polymers or products (A. Zanchet et al., 2019).

Plasticizer can reduce rubber viscosity, hence improving processing characteristics and filler dispersion. These petroleum-based plasticizers with low molecular weight have a tendency to volatilize during heat processing. This causes the rubber compound with poor mechanical qualities (Maceiras et al., 2017).

2.7 Review on Rubber Compound Performance

Polyisoprene was the world's first commercially produced elastomer, generally formed from latex of the Hevea Brasiliensis, and a synthetic version was manufactured on a huge application during World War 2. Polyisoprene substances, whether natural (NR) or synthetic (IR), are both affordable and have a mix of suitable physical qualities, which include a low dynamic response, low hysteresis and increased levels of durability. They are being used extensively, especially for transportation purposes, such as tyres, anti-vibration dampers other diverse applications (Kind et al., 2012).

The major reason for chemically changing natural rubber was to improve the rubber compound properties. The rubber compound can overcome shortcomings such as low heat resistance, poor oil resistance, or low abrasion resistance. Environmental issues are becoming increasingly important in the modern-day. This is because natural rubber is a renewable resource. It also becoming more desirable in a wide variety of uses. There has been a surge in research into the chemical modification of natural rubber to develop new applications (Shinzo et al., 2014).

Due to their simplicity of manufacture, polymer composites saw the most widespread and diverse application of composites. Rubber is a widely utilized polymeric matrix due to its excellent energy absorption capabilities (Ahmed et al., 2013). It is far more elastic than other materials and may revert to its original shape without lasting distortion once the load is removed. There are many applications of natural rubber compounds.

Different types of natural rubber compounds have different properties. This can be controlled by the material that is added to the compounds and process. One of the processes is vulcanization to produce the natural rubber compound. With the invention of effective vulcanization methods, the manufacturing of high-quality rubber on a wide scale and at a low cost expanded significantly. Different rubbers are combined with a variety of components and additives depending mostly on the final application of the natural rubber compound (Fazli et al., 2020).

2.8 Scanning Electron Microscope (SEM) Observation

Within the column, magnetic lenses focus the beam onto a tiny diameter probe. The column's scan coils raster the probe across the sample surface contained in the chamber at the column's end. To enable electron beam generation as well as advancement, the gun, column, and samples chamber are kept in vacuum. The electrons in the beam pierce a few micrometres into the surface of a bulk sample, engage with its atoms, but also produce a variety of signals including such secondary and backscattered electrons, as well as characteristic x-rays, which are collected and analysed to obtain images and information about the specimen's surface chemistry (Khairi et al., 2019).

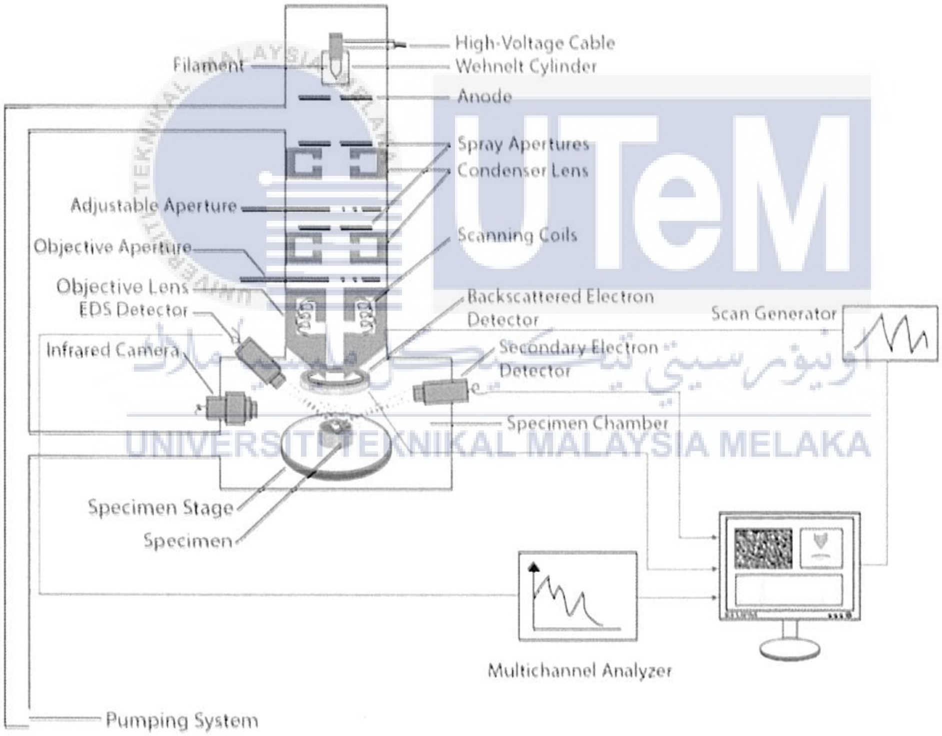


Figure 2.8: Systematic diagram of SEM

2.9 Summary

Chapter two introduces the basic and primary concepts behind all types of processing oil (PO), such as waste cooking oil, transesterification waste cooking oil, and rubber compound. The chapter examinedthe analysis of relevant literature and earlier papers on rubber compounds, their applications,uses, and qualities. Then, for the sake of clarity, the testing procedure from another earlier research is incorporated in this chapter. Additionally, this chapter detailed the transesterification process of waste cooking oil as a sustainable alternative to synthetic processing oil. It was also reported to be one of the finest processing oils evaluated. Nevertheless, this chapter will be beneficial and provide guidance on conducting theexperimental stage.

CHAPTER 3

METHODOLOGY

This third chapter summarises the entire experimental flow required to accomplish the research's objectives. The methodology for this research covered the steps taken to compare the study. The methodologies mentioned are included the raw materials characterization, experimental procedures starting from the form sample preparation and testing, and all associated metrics correspond to the American Society for Materials and Testing's standard (ASTM).

3.1 An Overview of Methodology

Threre are three distinct experimental stages which comprise the entire methodological approach, as described in Chapter 1. The first stage has begun with the preparation of raw materials, FTIR analysis, and further characterisation. Following that, the fabrication of a sustainable rubber compound was examined and validated using the processing oil. Finally,the validated sample production is physically and mechanically tested using produced samples with 0 phr processing oil in natural rubber compound.

From the following Figure 3.1, it has shown that the flow chart of the research and the overall experiment process. The research and the experiment have started with the preparation of the processingoil. This has included the waste cooking oil, and treated cooking oil. The goal was to determine the potential use of all the processing oil. This can be evaluated by performing the mechanical and physical testing to the fabricated rubber compound. The testing that was included are the tensile testing, density testing and Shore-A hardness testing. Upon after the result is obtained from the testing, we can define the potential use of the processing oil.

The parts that follow in this chapter provide further explanation on procedural that were carried out to accomplish this research objectives.

The first objective was to evaluate the effects of loading variation (0 phr, 5 phr, 10 phr, 15 phr, and 20 phr) for two different types of proceesing oil to the cure characteristic of natural rubber compounds through oscillating cure rheometer.

Next aim is to assess the influence of varying loading addition to mechanical and physical characteristics of natural rubber compounds by performing various associated testing which are tensile test, Shore-A hardness test, and density analysis.

Last but not least is to correlate the plasticiser effects of green processing oil with the fracture morphology of natural rubber compounds using the Scanning Electron Microscope (SEM) observation.

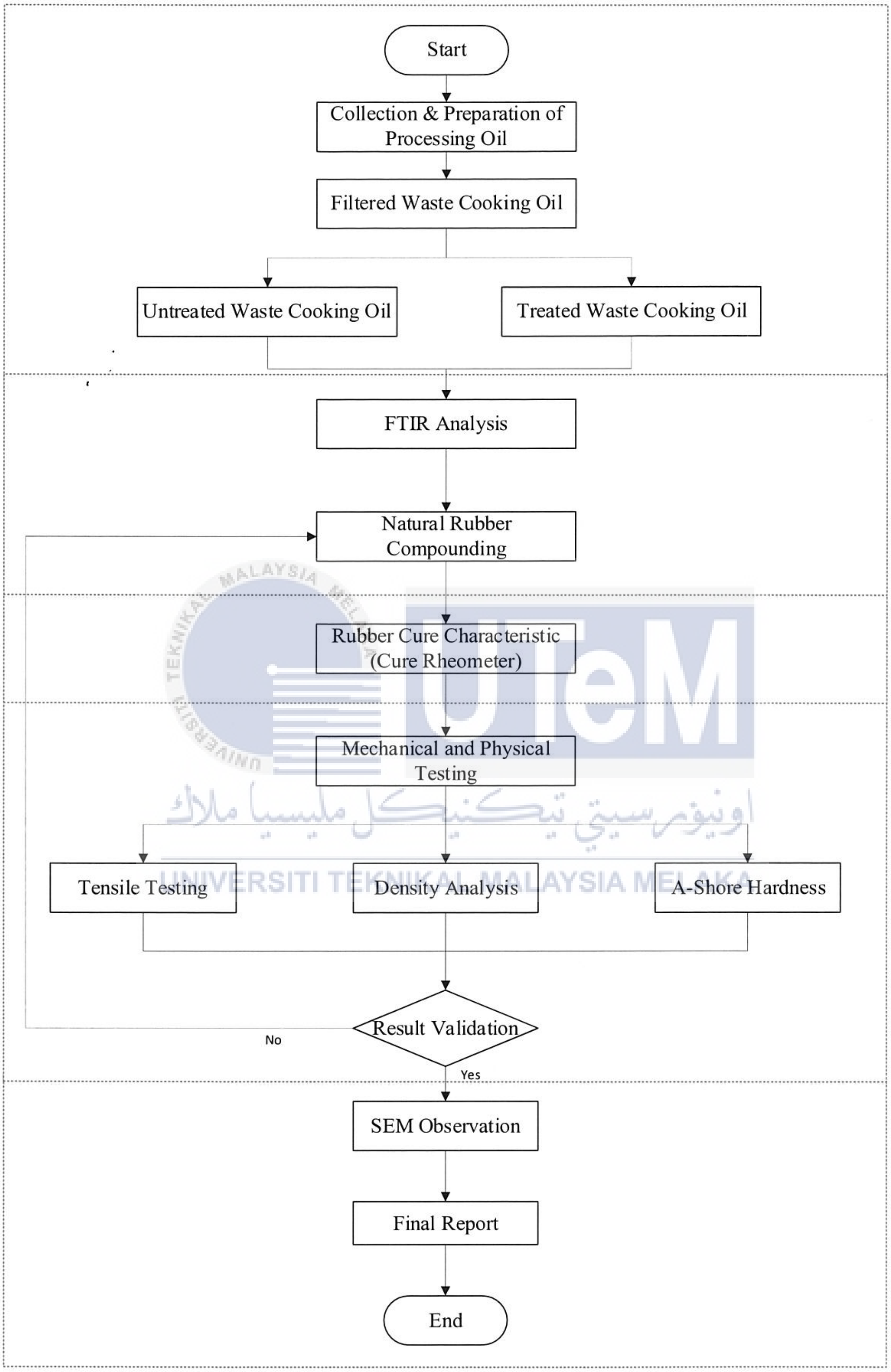


Figure 3.1: Flow Charts of the experiment

3.2 Collection of Processing Oil

Following the step for the collection of all the processing oils involve in this research.

3.2.1 Waste Cooking Oil (WCO)

The manufacturing of waste cooking oil is defined as the function of cooking temperature and the time of consumption utilised for frying. Waste cooking oil are composed from the local restaurant in Melaka. The samples of oils used was collected from the fryer that was used for cooking food such as potatoes and culinary items. Twenty-five liter of oil samples was acquired from a containment drum in which WCO as collected once every day for one week. The samples oils are believed to be typical as it is acquired from the storage tanks for 8 to 10 weeks from batch to batch of waste oil. The temperature noted when frying was in the variation of 130ºC - 175ºC. This temperature is related with the temperatures (140ºC - 180ºC) to prepare the french fries. Nevertheless, it was challenging to evaluate the temperature in hot oil that offers around 5 to 10 percent error. Dependent to the quantity of foods used for frying, the oil had decreased from time to time at the end of each day and once in three days.

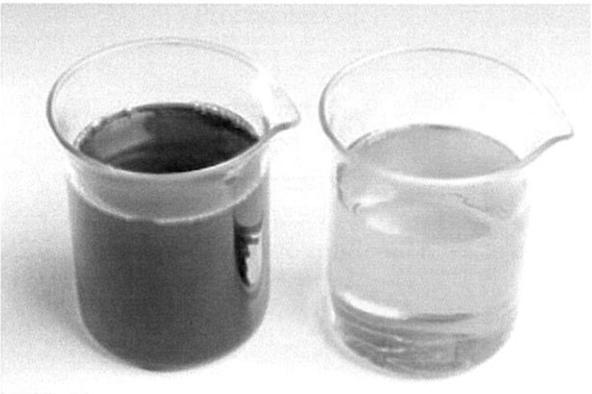


Figure 3.2.1: Waste Cooking Oil

3.2.2 Treated Waste Cooking Oil (TWCO)

Next is for the treated waste cooking oil. The process starts with collection ofwaste cooking oil. The oil was modified via the transesterification process for allowing the OH group to be presence in the processing oil. The following Figure 3.3.2 is the flow chart of the treated waste cooking oil procedure.

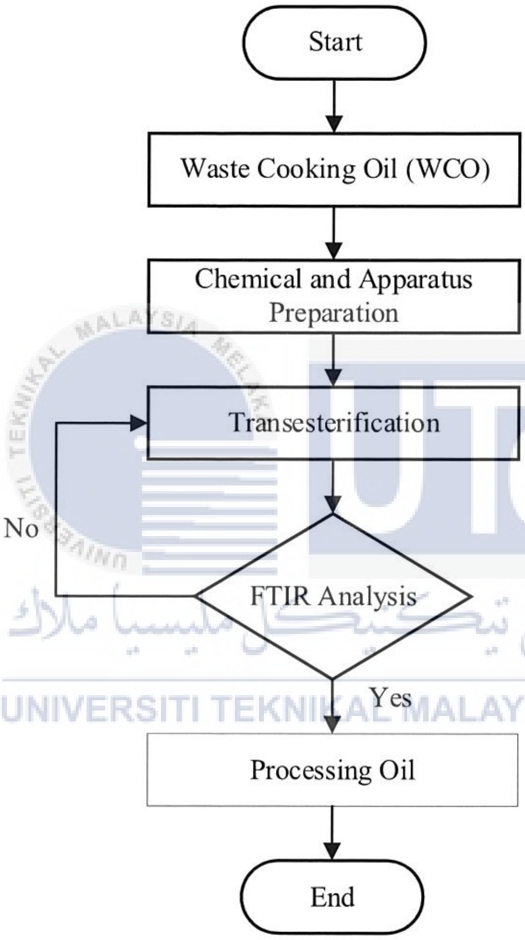


Figure 3.2.2: Flowchart for transesterification waste cooking oil.

As shown in the Figure 3.2.2, the next step for the waste cooking oil is transesterification. The procedure of transesterification is used to lower the viscosity of waste cooking oil. This approach or procedure may be accurate if the free fatty acid (FFA) content is less than 2%. Hydroxide will be used as a homogeneous catalyst in this process. The reaction was carried out with 1% of catalyst content. Before undergoing transeserification, the WCO was combined with sodium hydroxide (NaOH 5%) in the same container. The solvent was then mixed using agitator speed until it became dull. The solution was then heated to roughly 60° C for two hours.

Next step is the Fourier Transform Infrared Spectroscopy (FTIR) analysis. As mentioned before, in order to make processing oil, the hydroxyl group must be present in waste cooking oil. The waste cooking oil is now turned into the treated waste cooking oil after it has been undergone the transesterification process.

3.3 Waste Cooking Oil Filtration

For the preparation of the oils, there are few steps to be done. Right after the collection of the waste cooking oils, all of it must be filtered. First it was filtered with the normal filter. Each of the oil is filtered twice by using the coffee filter. Following is the Figure 3.3.1 showing of before and after the filtering. The unwanted particle can be viewed by our naked eyed.

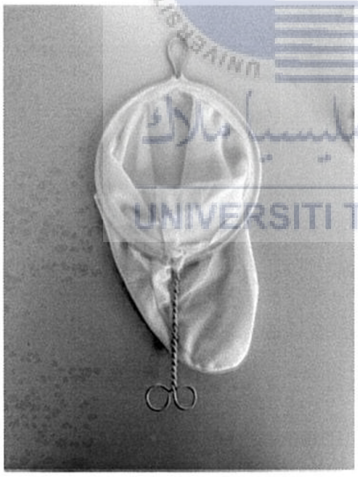
Before	After
	

Figure 3.3.1: The image of filter at before and after filteration of the WCO

Next step would be to filter the oil with vacuum filter (Rocker 300). The vacuum filtration is utilised between both the suction cup and the vacuum generator to remove almost all tiny particles such as dust that are sucked from the environment. It can be ensuring that the captured particles are equally distributed over the filter membrane, making it ideal for measuring and analyzing the particulate matter. Filtration is a method for separating solids from liquids, although it may also be done with the help of gravity. The waste cooking oil is filtered twice by using this method. Following is the Figure 3.3.2 is the setup for vacuum filtration.

Figure 3.3.2: The setup of vacuum filtration for WCO.

3.4 Transesterification Process

Transesterification is a method that is used to decrease the viscosity of used cooking oil (WCO). If the free fatty acid (FFA) content is less than 2%, the transesterification method is success. Hydroxide was used as a homogeneous catalyst for this process. The reaction was carried out with 1% catalyst. Before the transeserification process, hydrogen peroxide and methanol were blended in the same bottle. The solvent was then mixed at the agitator speed until it became dull. They were heated for two hours to around 60° C.

For the following step, is the pre-treatment for the waste cooking oil. 100g of waste cooking oil is heated up to 220°C with the hot plate. Next, add ginger with size of 3mm or 3.33g. At the same time, strirring the ginger using magnetic stirring rod for 10 mins. After that, the hot plate was turn off and the ginger is removed. The oil was then added with 3mm or 3.33g asam keping. The mixture is then left for 24 hours. Following is the Figure 3.4.1 of the ginger being added to the oil.

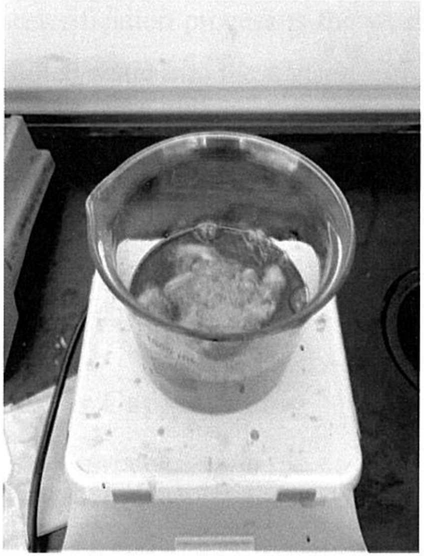


Figure 3.4.1: Pre-treatment of waste cooking oil.

Following step is the transesterification process of waste cooking oil. About 100g of the pre-treated waste cooking oil (WCO) was heated up to 60° C and keep the temperature constant. Then, 600 ml of methanol is added. The ratio of methanol used is 6:1 of the WCO. 14 ml of Sodium hydroxide (NaOH) is also added as the catalyst. The mixture is wrap with the parafilm to avoid the evaporation. It then stirs for 60 min with the constant temperature. After 60 minutes, the mixture sits for 24 hours for the separation of the gycerol and ester (Anisah et al., 2019).

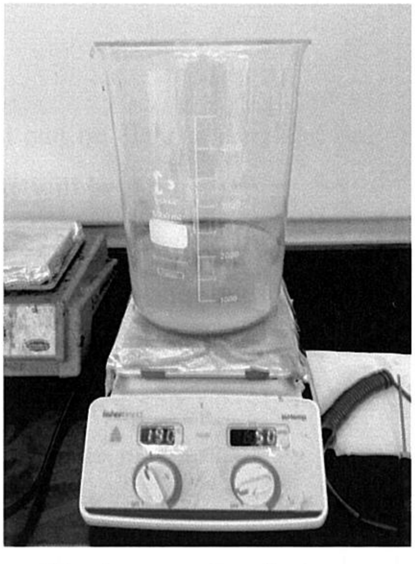


Figure 3.4.2: Transesterification procedure for waste cooking oil conversion.

Last step for the transesterification process is the washing process. The mixture is added with 100 ml of 50°C distilled water into the transesterified oil. The mixture is shaked. Let the mixture then sit for few hours for the separation of oil and water. The process is repeated untill the cloudy distilled water turns clear. The oil is collected and was heated up to 100° C to remove the excess water.

3.5 Parameter of the Rubber Compounding

As stated in the scope for this study in Chapter 1, two types of recycled processing oil are used. These processing oils are waste cooking oil, and treated waste cooking. The following Table 3.5 for the parameter of study which focusing to the effect of processing oil loading variation into the natural rubber compound.

Table 3.5: Parameter of the research work.

No.	**Type of Rubber**	**Type of Processing Oil**	**Loading Variation (phr)**
1	Natural Rubber	Waste Cooking Oil	5
			10
			20
2		Treated Waste Cooking Oil	**5**
			10
			20
3		Control Sample	0

From the Table 3.5, it can be clearly seen that only natural rubber was used. The loading variation for this study will be 5 phr, 10 phr, and 20phr for each type of processing oil. The 0 phr of processing oil is utilized as the control sample in this study. This concludes that the total samples are seven, including the control sample. Next, each result of the loading variation on the natural rubber compound was compared with the control sample. The treated waste cooking oil filled natural rubber compund is expected to be better in performance than the untreated waste cooking oil. The mechanical and physical testing is carried out with regards to the loading variation of processing oil. In the next section, the testing method and procedure which performed this study was explained in details.

3.6 Viscosity Measurement

Viscosity may be measured in a variety of ways, depending on the kind of substance and the conditions. It is necessary to suspend the rotor and attach the measurement cup to the device (HAAKE Viscoster 1 plus). Submerge the rotor until the dip mark on the rotor shaft is reached in the substances. Operate the instrument and hold it upright by hand or with the stand mount. The measurement is obtained from the display. The value on the left represents the rotor, while the value on the right represents viscosity. Following is the Figure 3.6 of the viscosity measurement.

Figure 3.6: The setup of apparatus for viscosity measurement.

3.7 Fourier Transform Infrared Spectrometry (FTIR)

The hydroxyl group was identified in the molecular structure of waste cooking oil (WCO) and treated waste cooking oil and tranesterification waste cooking oil using FTIR (FT/IR-6100, JASCO). It was important for the hydroxyl group to be present in waste cooking oil in order to make it as processing oil. FTIR is a critical characterisation tool since it developed the spectrum of chemical bonds including functional groups' infrared absorption. Both spectra have awavelength range of 1000–4000 cm^{-}1 and thus are registered at 2.00mm/s scan rates with a 7.1mm width. FTIR equipment is as shown in the following Figure 3.7.1.

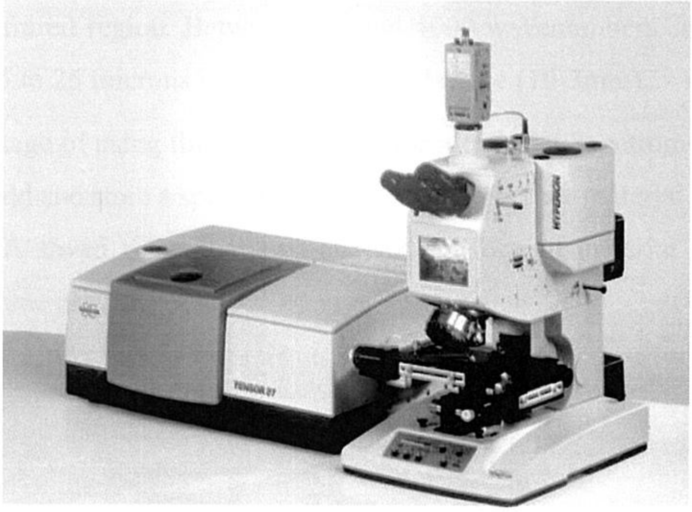


Figure 3.7.1: Fourier Transform Infrared Spectroscopy (FTIR)

The interference pattern between the two light beams is measured using an interferometer or "interference metre." The interferometer is illustrated with light from such an infrared source coming from the left. Just after two light beams had travelled, they are recombined to form a single beam, which then exits at the interferometer. (Smith, 2011). Following Figure 3.7.2 shows a simplified diagram of an interferometer.

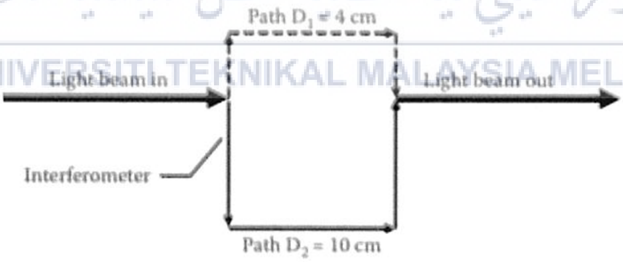


Figure 3.7.2: A simplified diagram of an interferometer

The standard which includes for the Fourier Transform Infrared Spectrometry (FTIR) are ASTM E168 and the E1252. The scope for using this Fourier Transform Infrared Spectrometry is the material which does not absorb the infrared light, the spectral scan cannot be obtained. The very first rational step in identifying a polymer is to use FTIR. Additionally, FTIR is used for material quality control and contamination analysis on both the external and internal surfaces. The common infrared scan is generated in the light spectrum's mid-infrared region. Between 400 and 4000 wavenumbers correspond to wavelengths of 2.5 to 25 microns in the mid-infrared range (10-3mm).

The advantage of using this Fourier Transform Infrared Spectrometry (FTIR), it is possible to build and store a spectral scan of even a reference material in a spectral library database. A saved reference scan enables subsequent material scans to be compared to the same previous scan.

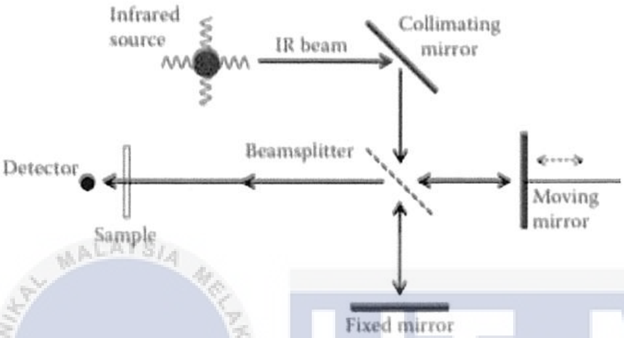


Figure 3.7.3: The optical diagram (Michelson) interferometer

For the internal polymer contamination, FTIR can be utilized. The quantity of contamination that may be detected is dependent to the base polymer and the contaminant's spectral scanning. Contamination involving materials with extremely dissimilar infrared spectra is typically detectable at a level of about one to two percent. Contamination caused by materials with comparable infrared spectra may be undetectable at even the ten percent level.

Meanwhile for the surface contamination, it can be analyzed by using normal reflective of FTIR. This is due to only few microns of the beam of infrared enter the surface. Last step is a liquid wash is performed by rinsing the sample with a solvent that is non-destructive to the sample. On the FTIR reflective sample area, a solvent wash of the sample's surface is collected and evaporated to dryness. After the solvent is evaporated, the solvent wash residue is analysed using FTIR.

3.8 Natural Rubber Compounding

The standard natural rubber compounding was used in this study. In the following section, provide is the natural rubber formulation. The sample preparation was also included.

3.8.1 Natural Rubber Formulation

In the following Table 3.8.1, it shows the formulation of natural rubber compound. These added chemicals will be constant variable for this study. The natural rubber was compounded by using an open two-roll mixing mill. The friction ratio is 1:3 and operated at temperature of 35°C. The time taken for mixing of the natural rubber compound is within 20 minutes. The composite weight was estimated around 1.5 kg.

Table 3.8.1 Natural Rubber Formulations is based on the prior study (Syamin et al., 2017).

Mix number	**1**	**2**	**3**	**4**
SMR L	100	100	100	100
Stearic Acid	2	2	2	2
Zinc Oxide	5	5	5	5
Antioxidant	3	3	3	3
HAF	50	50	50	50
CBS	0.75	0.75	0.75	0.75
Sulphur	2.5	2.5	2.5	2.5
Process Oil	**-**	**5**	**10**	**20**

*There are 2 types of proccessing oil are being investigated.

3.8.2 Sample Preparation

Compressive moulded specimens were fabricated with a curing temperature of 160°C and a pressure of 10 MPa, as well as the hot press hydraulic presses are electrically heated at the appropriate vulcunization period as determined by an oscillating disc rheometer. (Aline Zanchet et al., 2016).

3.9 Rubber Cure Characterisation using Cure Rheometer

Data from an ODR are used to determining the vulcanization period. The cure characteristic properties of the natural rubber compounds were determined in the ODR Tech Pro-Rheotech OD+ rheometer using ASTM D 2084–06 at 160°C vulcanisation temperature. The Oscillating disk rheometer using for cure characterization is shown as in the following Figure 3.9.

Figure 3.9: Oscillating disk rheometer using for cure characterization.

3.10 Performance Testing

This section had discussed the testing and characterization of rubber compounds. The entire testing was utilized to accomplish the objectives stated for this research. As for the testing standard, the ASTM are fully used.

3.10.1 Mechanical Testing – Tensile Testing

The tensile testing is performed by using the ASTMD1822 which is the ASTM Standard Test Method for rubber. The place of conducting this test is in *Nano Material Technology Lab* (Performance Testing Area) at Faculty of Manufacturing Engineering (Universiti Teknikal Malaysia, Melaka). Tensile tests determine the force required to fracture the rubber sample specimen and the extent to which the specimen stretches or elongates to reach into that point.

By using the Wallace die cutter, the 2mm thickness of moulded specimen in dumbbell shaped is obtained. The tensile testing was conducted at a crosshead speed of 500 mm/min by using an the Instron model 3366. The testing was conducted at a temperature of 25 ±2˚C (Norhazariah et al., 2016). The configuration of the tensile testing sample is shown as in the following figure 3.10.1.

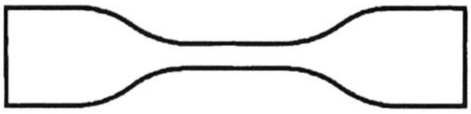


Figure 3.10.1: Shape of rubber compound for tensile testing (Dumbbell shaped)

The following Equation 3.1 and 3.2 can be used to compute the tensile modulus and tensile strength repectively.

$$Tensile\ Modulus\ (MPa) = \frac{Stress\ (Pa)}{Strain\ Difference}$$

Equation 3.1

$$Tensile\ Strength\ (MPa) = \frac{Pulling\ Force\ (N)}{Sample\ Thickness(mm) \times Sample\ Width\ (mm)}$$

Equation 3.2

3.10.2 Physical Testing – Shore A Hardness

The hardness test for cured rubber compound was carried out in accordance to Shore-A hardness standard of ASTM D 2240. Usually, the durometer is used to evaluate the relative of the hardness of rubber or plastic. The test is used to determine the penetration depth of a specific indentor into a specified material underspecified force and time circumstances. The hardness value is frequently used to identify and specify elastomers' hardness or perform quality control on large quantities of material. Figure 3.8.2 is the shore A hardness tester.

Figure 3.10.2: Shore-A for hardness testing

The elasticity of a material is determined by its hardness. The hardness values are calculated using a scale. The Shore A hardness levels are widely used, with the A scale indicating softer materials and the D scale indicating more rigid materials. The porousness of a material is proportional to its hardness (Dick, 2003).

The penetrates a hard ball indenter into a rubber test piece to determine the degree of penetration. By utilising test pieces with a diameter of 12 mm and a thickness of 2 mm. Prior to testing, samples are conditioned for at least three hours at a typical laboratory regulated temperature of 25 ° C. The hardness reading was taken using a dial gauge that has previously been calibrated in accordance with the International Rubber Hardness Degree (IRHD). Between the indentation and the measurement, a reading was obtained at a continuous interval. This is critical since the rubber's measured resistance to the indenter reduces with time. The longer the time period, the lower the value of hardness. The reading was collected shortly as the pressure foot made solid contact with the sample, within a fraction of a second. The depth ofthe indentation was measured.

3.10.3 Physical Testing – Density

The density and the specific gravity test are based on the ASTM D792 and ISO 1183. Relative density is the mass of a material compared to the mass of an identical volume of a reference substance (typically water) and is thus dimensionless.The specific gravity of a substance is defined as the mass ratio of that substance at 23°C to that substance in deionized water.

$$Specific\ Gravity = \frac{a}{(a + W) - b}$$

Equation 3.3

a = mass of specimen in air.

b = mass of specimen and sinker (if included or used) in water.

W = If used, mass of completely immersed sinker with partially immersed wire.

$$Density, kg/m^3 = (Specific\ Gravity) \times 997.6$$

Equation 3.4

Specific gravity was formerly a famous phrase for relative density, but it is obsolete and should never be used. In practice, determining the relative density versus water is a common way of measurement, although the volume is assumed to be 1 Mg/m. The density of a polymer is reported at 0.01 Mg/m, and the most frequent testing technique is that by weighing in water and air.

3.11 Scanning Electron Microscope (SEM) Observation

The aim of observing the fracture surface of natural rubber compound samples using the Scanning Electron Microscope (SEM), as represented at the following Figure 3.11. The machine was to explore the morphological behaviour of the fracture surface due to mechanical. The broken surface was sliced and put on the stub, followed by a gold palladium coating. This process was carried out in order to avoid electrostatic charging throughout the observation time, which degrades the observation's quality. By scanning thesample with a powerful electron beam at an average acceleration voltage of roughly 40 kV,the fracture morphological structure will be determined. The observation was magnified 50x,100x, 300x, 500x, or 1000x. Each magnification scale has been assigned for three different positions.

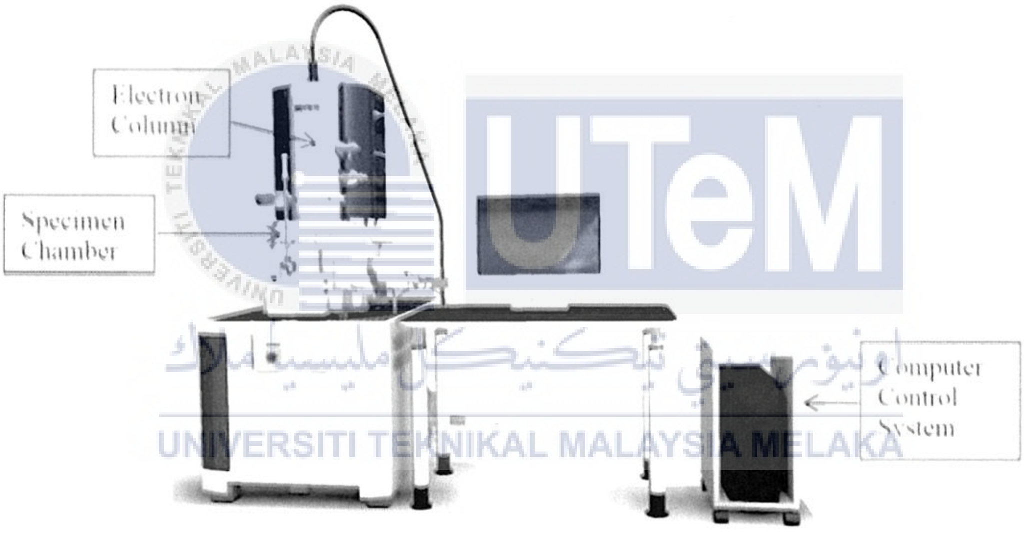


Figure 3.11: Scanning Electron Microscope (SEM) for fracture surface morphological observation

3.12 Summary

This chapter details the entire experimental procedure necessary to accomplish the primary objectives. The principle that was used to accomplish the analysis was incorporated into the research methods. Ultimately, all methods discussed thus far have included the categorisation of raw materials as well as the experimental methodology for sample processing and testing of relevant steps, both of which are based on the American Society for Materials and Testing standard (ASTM). The summary for the procedure whichused for this research's work can be summarized as below:

1. Preparation of raw materials.

The waste cooking oil is collected from the local restaurant. For the treated waste cooking oil, the waste is undergone the transesterification process. The transesterification process is used to lower the viscosity of waste cooking oil.

2. Preparation of Natural Rubber.

The natural rubber compound is prepared by using an open two-roll mising mill at 35 ° C for 20 minutes.

3. Vulcanization of Natural Rubber Compounds.

Vulcanization of the natural rubber compound is accomplished by utilising a hot press machine set at 160 degrees Celsius and 10 Mpa.

4. Testing

The mechanical test (tensile test) and physical test (hardness test and density) involved in this research work. This is to determine the performance of natural rubber compound. For the characterization, the scanning electron microscope (SEM) is used.

CHAPTER 4

RESULT AND DISCUSSION

This chapter present and discusses the experiment data analysis performed following the sample fabrication and multiple testing methods. In order to validate the discussion of the results, additional support from another prior research which is comparable simillar is used. All tables, graphs, and figures, as well as the micrograph, are represented and presented in a manner that facilitates comprehension and enriches the outcome discussions.

4.1 Overview

The main purpose of this research is to transform the waste cooking oil (WCO) into processing oil (PO) for natural rubber compound by using the transesterification method. The parts per hundred rubber of processing oil loading to rubber compound were varied into 0 phr, 5 phr, 10 phr and 20 phr. The elongation at break, 300% modulus and tensile strength testing were used to analyse the tensile mechanical properties. For the analysis of physical properties, mooney viscosity, shore A hardness, specific gravity and density analysis were used. Moving die rheometer (MDR) was used to analyse the cure characteristics of rubber compound's sample that loaded with varies number phr of waste cooking oil and tranesterificatied waste cooking oil as sustainable processing oil. Finally, the scanning electron microscopy (SEM) was used to observe the fracture morphology of natural rubber-based compound and also to relate the plasticiser effects. Since the sample is not conductive, thus it needed to be coated with gold by using sputter coating. However, the sputter coating machine is not available due to maintenance in the lab. Thus, the option that available are the variable pressure scanning electron microscopy (VPSEM). Further elaboration and discussion were made available at the subchapter 4.7. The FT-IR analysis which was discussed on next subchapter was used to identify the sucess of transesterification in the waste cooking oil.

4.2 FTIR Analysis

Generally, FTIR spectroscopy is a method to identify polymeric, organic and inorganic substances. The FTIR technique of analysis utilizes infrared light to evaluate the chemical characteristics of test specimens. For this study, FTIR approach was utilised in order to determine the proportion of waste cooking oil that was converted into biodiesel during the transesterification process.

An infrared midrange analysis was performed on the samples in the area stretching from 400 to 4000 cm^{-1}. This analysis covered the absorption bands that are indicative of biodiesel (methyl ester) as well as waste cooking oil. The spectra of waste cooking oil and transesterification waste cooking oil is slightly difference at some area which is around 1425-1447 cm^{-1} and 1188 -1200 cm^{-1} (Siatis et al., 2006). For the region which related to the C=O bond is around 1700 – 1800 cm^{-1}, meanwhile the region from 2800 – 3000 cm^{-1} is associated to CH stretching olefins (Siatis et al., 2006).

In the wavenumber band of 3450–3250 cm^{-1}, all of the FTIR spectra exhibited a broad, identifiable peak. This effect may be caused by the stretching vibrations from hydroxyl groups (OH) in waste cooking oil molecules. In addition, absorption peaks at around 2960 cm^{-1} and 2910 cm^{-1}, which related to stretching vibrations of CH in the methyl as well as methylene groups. This reaction may be produced by the stretching vibrations of hydroxyl groups (OH^{-}) in waste cooking oil molecules. The absorption peaks also happened around the 2900-2850 cm^{-1}.

At peaks about 2930- 2920cm^{-1} and 2870-2860cm-^{1}, the detection of absorption peaks. This is also caused by the methyl group. Monosubstituted Benzene which corresponds to the C-C of stretching vibration at band 1600 cm^{-1} and 1590 cm^{-1}. The ring deformation vibration was at region 710-695 cm^{-1}. The absorption bands in the 1620 – 1450cm^{-1} area of the spectra of modified benzenes are sensitive to minor changes in position and significant changes in strength.

Furthermore, since biodiesel is mostly monoalkyl ester, the strong C=O stretching band of methyl ester is seen at 2750 - 1735 cm^{-1} (Chien et al., 2009). It is also known as the aliphatic and olefinic esters. This is mainly due to the C=O which stretched at region 1744

– 1739 cm^{-1} at very strong intensity. Similarly expected are the medium C-O bands at 1252, 1210, and 1160 cm^{-1}(Siatis et al., 2006).

The spectra of the transesterification of the waste cooking oil is as shown in Figure 4.2.2. Ester were the only catalysts that showed the peaks in 1750 – 1735 cm^{-1} band (Mahamuni & Adewuyi, 2009). This shows that the processing oil with a strong basic site which favor the transesterification process. Transesterification of waste cooking oil's FTIR spectrum hed revealed a C=O stretching band at 1743 cm^{-1} and C-O regions at 1252, 1200, as well as 1175 cm-^{1}. The FTIR spectra of its particle emissions closely matches those of the used fuel (Rosset & Perez-lopez, 2019).

Based on table 4.2.1, the differences of compound between the tranesterification waste cooking oil and the untreated waste cooking oil has been summerized. There are 9 major compound which can found on the FTIR analysis of both processing oil. The compounds are alkanes, ester, polyethers, cyclohexane, azo compound, trianez, nitrogren compound, sulfer compound and phosphorus compound. There are fews compounds which still simillar even after the transesterification process. The different are almost 50% between the TWCO and WCO. Alkanes compounds can be found on the treated waste cooking oil and the untreated waste cooking. The impurities compound such as cyclohexane can be found on the FTIR of both processing oil. This strongly can be found on range 2933 – 2025cm^{-1} and 2857 – 2849cm^{-1}.

As mentioned on the earlier paragraph, to make sure that the transesterification process is sucess, ester compound must be a primary compound to search in this FTIR analysis. The ester compound are strongly can be found on few bands' ranges of the TWCO. Based on Table 4.2.1, clearly that the ester compound is unfound in the FTIR analysis of untreated waste cooking oil. However, compound such as anzo compound can be indentify on the analysis. Anzo compound is derivaties of diazine in hydrogens which replaced by hydrocarbly group. Anzo usually used as the dye and pigment in most industry. Next compound that indentify in the WCO is cyclohexance. This compound usually used to disolve resin or fat in the cooking oil manufacturing factory. Other compound which can be detected on the WCO are sulfur and phosphorus compound (Siatis et al., 2006).

Table 4.2.1: FTIR Analysis's for TWCO

Classification	**Group**	**Bond**	**Range**	**Intensity**	**Mode**
Ester	RCOOR	C=O	1750-1735	Strong	Stretching
		C-O	1210-1160	Strong	Stretching
	C=C-COOR	C=O	1740-1715	Strong	Stretcthing
		C-O	1300-1160	Strong	Stretching
	CICOOC	C=O	1750- 1730	Strong	Stretching
		C-O-C	1300-1100	Strong	Stretching
Alkanes	R(CH2)4-C	CH	2936-2916	Strong	Antisymmetric
		CH	2863-2843	Strong	Symmetric
		CH	1485-1445	Medium	deformation
		CC	750-720	Medium	Skeletal vibration
	R-CH2-R	CH	2936-2916	Strong	Antisymmetric
		CH	2863-2843	Strong	Symmetric
Polyethers	Polyethylene glycerol	OH	3450-3250	Medium-weak	Stretching
		CH2	2960-2910	Medium	Antisymmetric
		CH2	2900-2850	Medium	Symmetric
Impurities	Cyclohexane	CH2	2933-2925	Strong	Antisymmetric
		CH2	2857-2849	Medium	Symmetric

Table 4.2.2: Comparation of FTIR's Classification between WCO and TWCO

No	**Classification**	**Range**	**WCO**	**TWCO**	**Remarks**
1	Alkanes (R(CH2)4-C	2936 - 2916	√	√	
		2863 - 2843	√	√	
		1485 – 1445	√	√	
		750 - 720	√	√	
2	**Ester**	**1750 - 1735**	-	√	The identification of ester compound in the processing oil is very important to confirm the tranesterification. (Anisah et al., 2019)
		1210 - 1160	-	√	
		1740 - 1715	-	√	
		1300 - 1160	-	√	
		1750 - 1730	-	√	
		1300 - 1100	-	√	
3	Polyethers	3450 - 3250	-	√	
		2960-2910	-	√	
		2900-2850	-	√	
4	**Cyclohexane**	**2933 – 2025**	√	√	
		2857 - 2849	√	√	
5	Azo Compound	1550 - 1400	√	-	
6	**Triazenes**	**1550 – 1450**	√	-	
7	Nitrogen Compound	1500 – 1400	√	-	
8	**Sulfer Compound**	**500 – 400**	√	-	
9	Phosphorus Compound	800 – 580	√	-	

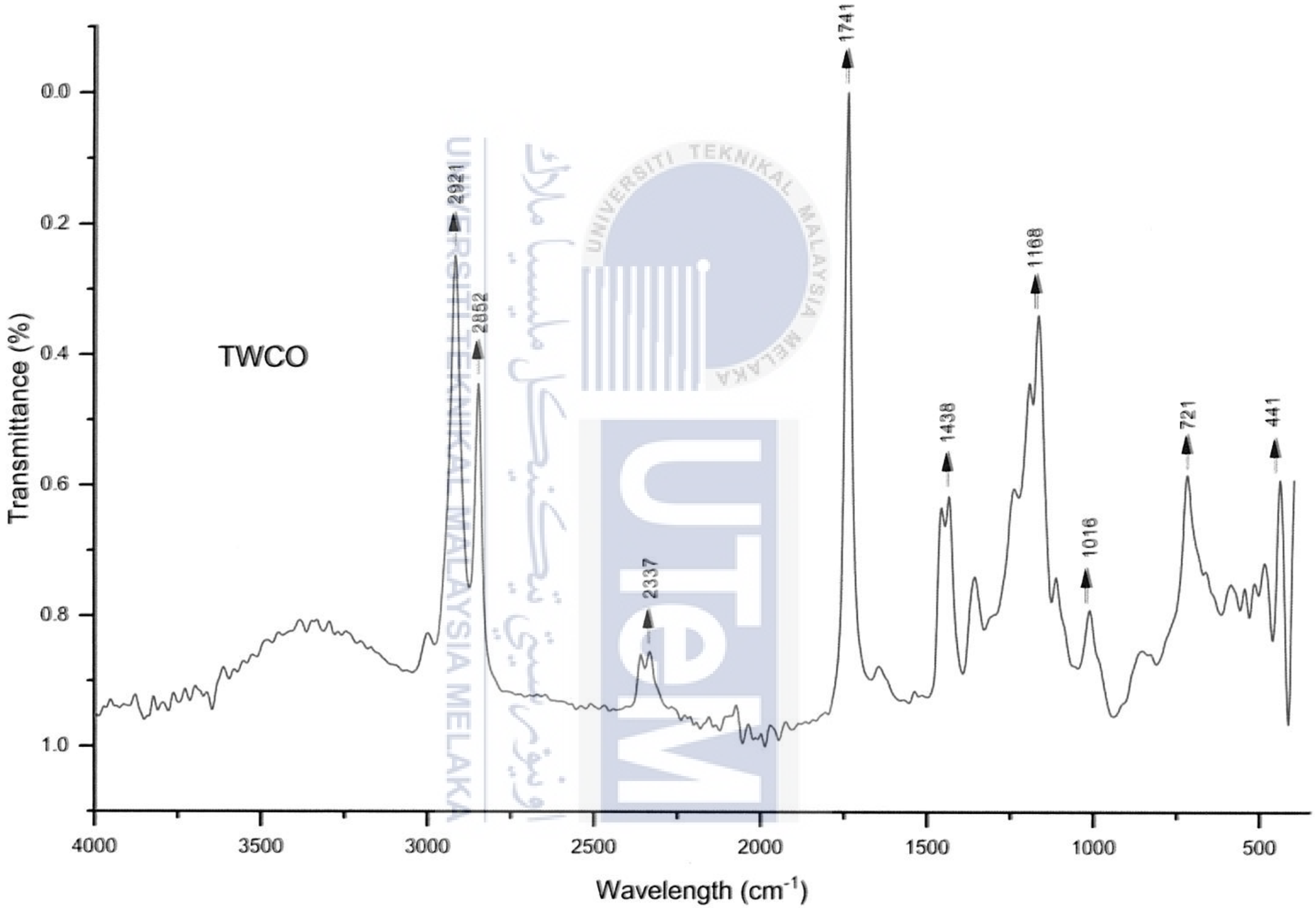


Figure 4.2.2: FTIR for the Transesterification Waste Cooking oil.

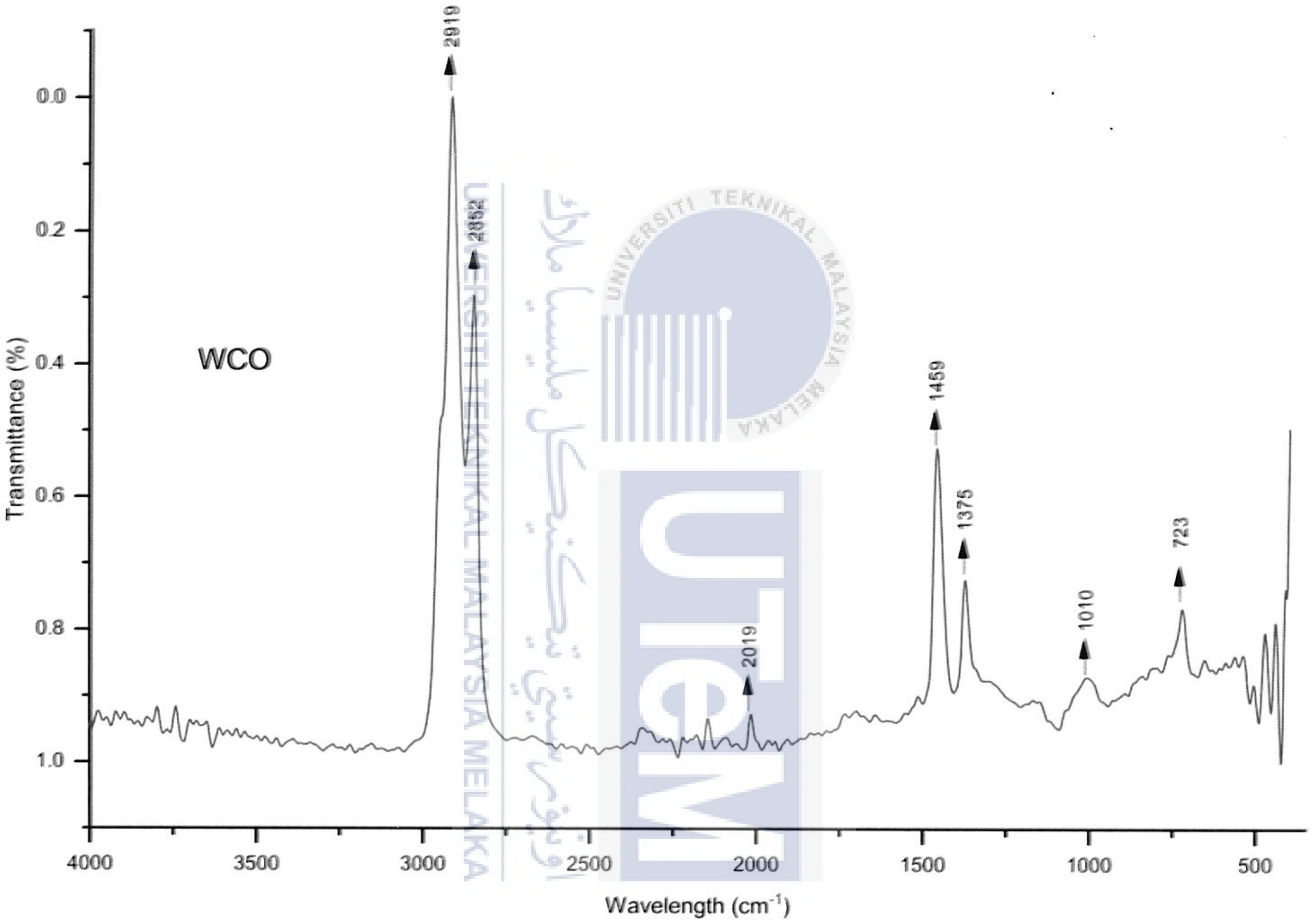


Figure 4.2.3: FTIR of waste cooking oil.

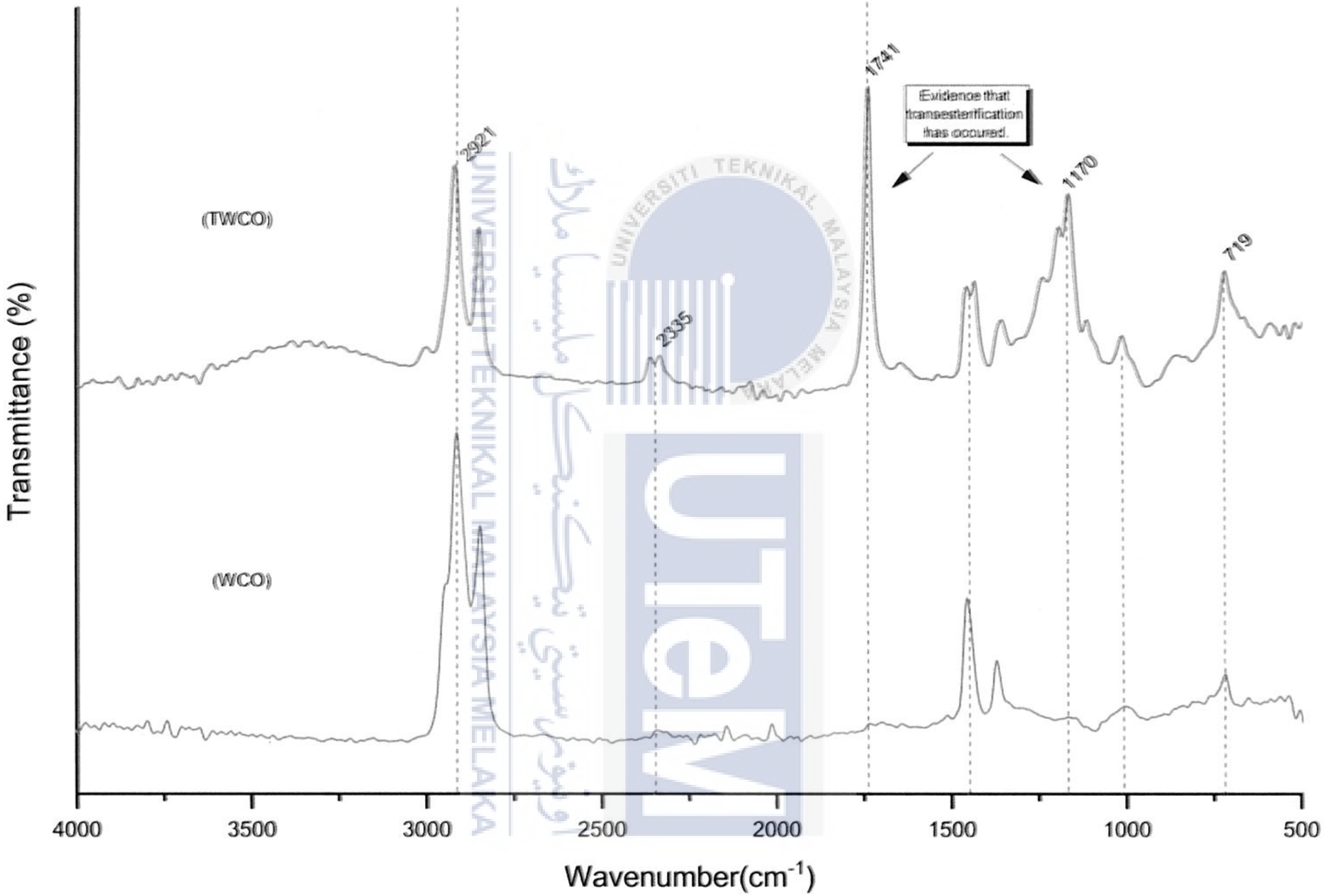


Figure 4.2.4: Comparation of FTIR between TWCO and WCO.

4.3 Dynamic Viscosity

The dynamic viscosity of liquid is the resistance to flow if exposed to an external force (Rotimi, 2016). This is a type of force generated that occurs when two horizontal planes are moved together. During the examination of liquid behaviour including fluid movements near solid boundaries, viscosity acts as an essential fluid characteristic.

$$\eta = Pascal * Second = \frac{N * S}{m^2} = \frac{kg}{m * s}$$

For the viscosity, it is a key property for lubricating liquids, such as lubricating oils and grease. Viscosity is the flow resistance caused by a liquid. Viscosity is inversely proportional to the viscosity of a liquid, hence fast-moving liquids like water have low viscosity while slow-moving liquids. Thus, honey-like liquids have a higher viscosity. For this study, the experiment was done in room temperature. Based on Table 4.3, the dynamic viscosity of TWCO is 500% higher than WCO. If the liquid has higher viscosity, the thicker the sample. Meanwhile, if the sample has lower viscosity, the thinner the sample. Based on prior research, it shows that the viscosity of processing oil affect the mixing energy of rubber compound (Boontawee et al., 2012). However, dynamic viscosity usally will drop very fast when the temperature is increased (Rotimi, 2016). Figure 4.3 shows the appearance of the waste cooking oil and the transesterification waste cooking oil. The appearance of waste cooking oil is dark brown and in form of viscous fluid. Meanwhile, the appearance of transesterification of waste cooking oil is pale yellow. Next subtopic had discussed about the cure characteristic analysis of rubber compound when loading with the TWCO and WCO.

Table 4.3: Dynamic Viscosity for WCO and TWCO

Type of Oil	**T1**	**T2**	**T3**	**T4**	**T5**	**Average (dPas) /Poise**
WCO	0.02	0.01	0.01	0.01	0.01	**0.012**
TWCO	0.05	0.09	0.06	0.05	0.05	**0.060**

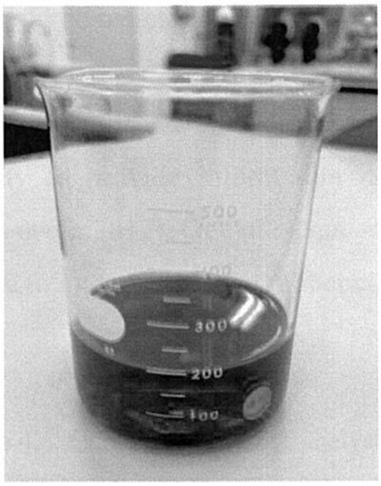
WCO	**TWCO**
	

Figure 4.3: Appearance Comparation of WCO and TWCO

4.4 Cure Characteristic Analysis

Moving Die Rheometer (MDR @ 160°C)

The characterization of the samples is for the waste cooking oil and the transesterified waste cooking oil. These processing oils are evaluated based on their tensile strength and hardness, which reflect the mechanical and physical properties of rubber compound samples.

As for the scorch time, the oil quantity increases due to diluents effect of the plasticizer but slightly decrease when 20 phr of processing oil is used. For the cure time, the result that obtained have simillar trend to the scorch time. From the result, better cure rate for oil-loaded samples is beneficial for increased manufacturing output, specifically for cooking oil varieties. The transesterification waste cooking oil have good plasticizing effect to enhance mixing by reducing the viscosity (ML) of the compound if compared to the waste cooking oil with value of 2.32 dNm for 20 phr of processing oil.

The lubricating effect reduces the inter-chain stresses and enhances the inter-molecular surface area (Saengdee et al., 2020). Then, softening and decreasing the viscosity of elastomers. The plasticizing impact at 10 phr is superior to that of the commonly used paraffinic oil in industry. From the MH's result, oil viscosity decrease correspondingly the cured elasticity (Pakhathirathien et al., 2016). As the result, the rubber compound can be enhanced even without changing the chemical. This showed that the processing oil changed the characteristic of the rubber compound. For the discolouration, there are no changes at before and after the rubber compound mixed with the transesterification waste cooking oil. This should be beneficial for the non-black vulcanised waste cooking oil to be used for the industry.

Ultimately, the result of cure characteristics is very important. This is due to the versatility to provide information regarding the property value and the processability (Syamin et al., 2017). One of advantage of using this method is that the temperature and the best time to manufacture the rubber compound can be identified.

Table 4.4: Cure characteristics analysis for rubber compound loaded with WCO and TWCO.

Sample	**Control 0**	**TWCO-5**	**TWCO-10**	**TWCO-20**	**WCO-5**	**WCO-10**	**WCO-20**
Low Torque, ML (dNm)	4.18	3.19	3.04	2.32	3.65	3.42	2.95
Max Torque, MH (dNm)	18.33	18.98	15.82	14.99	17.32	15.94	15.35
Induction Time, ts2 (secs)	125	121	148	146	135	149	152
Cure Time, tc90 (secs)	191	183	231	210	200	217	230

4.4.1 Low Torque, ML

When the rubber compound is heated with the help of compression pressure, generally the viscosity and torque will be decreasing. Thus, this low torque used to measure the viscosity and rigidity of the non-vulcanized rubber compound. To sum up, the higher the amount of processing oil is added to the rubber compound, it would reduce the rigidity of the rubber compound (Ismail et al., 2011).

Based on Figure 4.4.1, both processing oils affect the rubber compund's. For sample with zero phr of processing oil has the heighest low torque value. From the plotted figure, it shows that as the loading phr of processing oils are increased, the value of the low toque also decreases. When the five phr of processing oil is loaded to rubber compound, the low torque value is around 20% decrease is compared from the control sample of rubber compound. Both of rubber compound shows the lowest value of low torque ML when loaded with 20 phr with rubber compound. Usually, a lower value of rheometric torque is the indicator or implies the density of the rubber compound also reduce. However, increasing of number of lower torque is an indicator of the increasing interactions of the rubber compound (Masłowski et al., 2019).

Table 4.4.1: Low Torque's ML for rubber compound loaded with TWCO and WCO.

Sample (PHR)	**TWCO**	**WCO**
0	4.18	4.18
5	3.19	3.65
10	3.04	3.42
20	2.32	2.95

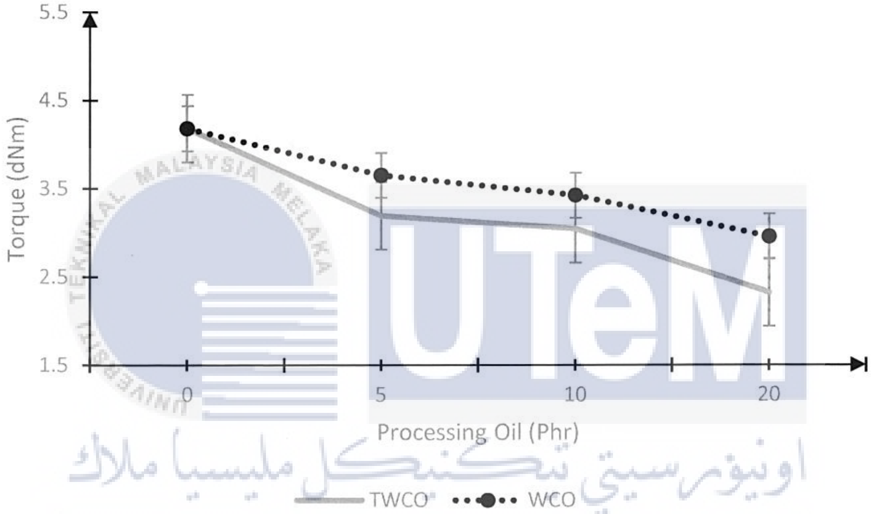


Figure 4.4.1: Low torque's ML Comparation of rubber compound loading with TWCO and WCO.

4.4.2 Max Torque, MH

In rubber compound, high or max torque represent higher degree of molecular crosskinking (Boontawee et al., 2012). Based from Figure 4.4.2, generally the results shows that the rubber portion which loaded with the processing oil is decreasing, as the amount of PO is increasing. However, when five phr of treated waste cooking oil is added to rubber compound, the max torque is 3% higher than the control sample. The result of max torque for rubber compound with loaded with 10 phr of treated waste cooking oil is almost same as the rubber compound added with the waste cooking oil. If compared to the control sample, the value of max torque is around 13% lower. The prior research also show that this max torque is due to fatty acid of ester that act as activator of vulcanization and promote crosslinking (Barlow, 2018).

Table 4.4.2: Max Torque's Table for rubber compound loading with TWCO and WCO.

Sample (PHR)	**TWCO**	**WCO**
0	18.33	18.33
5	18.98	17.32
10	15.82	15.94
20	14.99	15.35

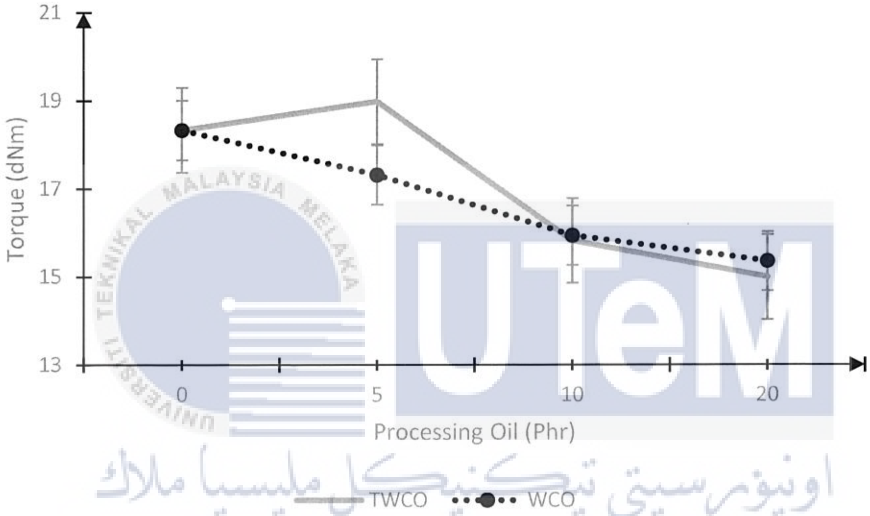


Figure 4.4.2: Max Torque's Figure for rubber compound loading with TWCO and WCO.

4.4.3 Scorch Time, ts_2

The scorch time (ts_2) is typically defined as the time until the initiation of vulcanization at a certain temperature and hence indicates the maximum processing time (Pechurai et al., 2015). This study shows that the scorch time is increasing as the content of processing oil loaded in the rubber compound is increasing. Figure 4.4.3 show the comparison of scorch time for rubber compound that added with the processing oil. The scorch time increasing as the amount of the processing loaded to the rubber compound increased. This is due to the fatty acid that contain in waste cooking oil (Pechurai et al., 2015; Indra Surya et al., 2019). However, the rubber compound which added with 5 phr of treated waste cooking oil has the lowest scorch time if compared to other. The scorch time is 3.2% lower than the control sample. Both of the sample has the highest scorch time when loaded with 10 phr of processing oil.

Table 4.4.3: Scorch Time's Table for rubber compound loading with TWCO and WCO.

Sample (PHR)	TWCO	WCO
0	125	125
5	121	135
10	148	149
20	146	152

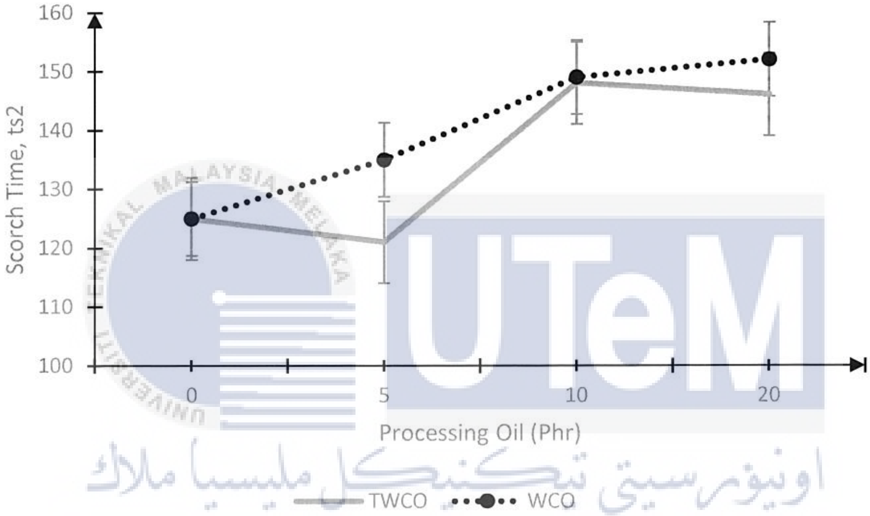


Figure 4.4.3: Scorch Time comparation of rubber compound loading with TWCO and WCO.

4.4.4 Cure Time, tc_{90}

In rubber compound, cure time is important and required for the vulcanization step to identify the crosslinking to happen thus producing the desired rubber compound with the disired properties (Pechurai et al., 2015). Figure 4.4.4 shows the cure time of rubber compound when loaded with the processing oil. It also can be seen that the cure time had increased as the content phr of processing oil loaded to the rubber compound is increased. Based on the result, for waste cooking oil, the cure time is increasing as the amount of processing oil increased. It shows that the cure time of rubber compound when added with 20 phr of waste cooking is 16% higher than the control sample. However, the cure time for rubber compound which loaded with 10 phr has 0.43% cure time faster than to 20 phr of waste cooking oil. The rubber compound with the lowest cure time is rubber compound that loaded with 5 phr of transesterification waste cooking oil. From the result of cure characteristic, the rubber compound can be enhanced even without changing the chemical.

Table 4.4.4: Cure Time's table for rubber compound loading with TWCO and WCO

Sample (PHR)	TWCO	WCO
0	191	191
5	183	200
10	231	217
20	210	230

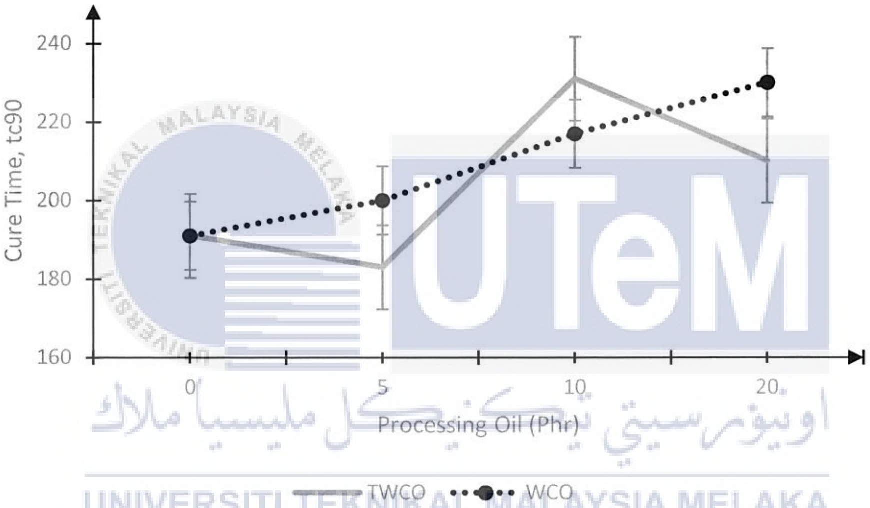


Figure 4.4.4 Comparation of cure time for rubber compound loading with TWCO and WCO.

4.5 Physical Testing

To understand the physical characteristic of produced rubber compound when added with processing oil, the physical testing was further carried out. About three physical testing were conducted which are the mooney viscosity, hardness (Shore A) and the specific gravity.

4.5.1 Mooney Viscosity ML (1+4) @ 100℃

Mooney viscosity evaluates the rigidity of uncured rubber compounds (Malá, 2011). Figure 4.5.1 show the mooney viscosity of rubber compound loaded with TWCO and WCO. Based on the plotted graphs, it shows that as the number of processing oil is increasing, the value of mooney viscosity is decreased which are similar to past finding by Siwarote et al., (2017).

The control sample shows the highest value of mooney viscosity. Meanwhile, the rubber compound which added with waste cooking oil of 20 phr has the lowest value of mooney viscosity. The result of control rubber compound is 26.10% lower than to the rubber compound that loading with 20 phr of treated waste cooking oil. When rubber compound is added with 5 phr and 10 phr of treated waste cooking oil, the result is almost the same (±1.08%). It is likely that vegetable oils might engage in sulphur vulcanisation processes, resulting in an increase in crosslinks, considering that vegetable oils include unsaturated fatty acids.

Table 4.5.1 Mooney Viscosity for rubber compound loading with TWCO and WCO

Sample (PHR)	TWCO	WCO
0	52.11	52.11
5	39.94	46.08
10	39.51	40.06
20	29.13	23.10

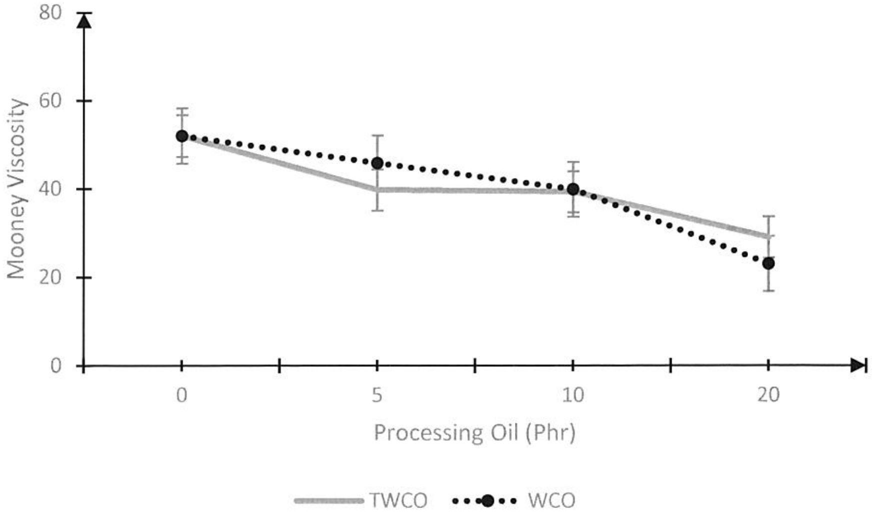


Figure 4.5.1: Mooney Viscosity's comparation for rubber compound loading with the TWCO and WCO.

4.5.2 Shore A Hardness Testing

In this study, shore A hardness is used to evaluate the hardness of the rubber compound which loaded with the processing oil. Shore A commonly used to measure the resistance of sample which has to indentation (Zanchet et al., 2012). Based on Figure 4.5.2, it shows the result of hardness shore A for rubber compound which added with treated waste cooking oil and waste cooking oil. The control sample show the highest value of hardness shore A. Based on the figure, it shows that as the number of processing oil is increasing, the value of hardness shore A is decreasing. Rubber compound which loaded with 20 phr of treated waste cooking oil as processing oil has the lowest value of hardness shore A value. If compared to the result of control sample, it was 22.22% lower.

The lubricating effect reduces the inter-chain stresses and enhances the inter-molecular surface area (Saengdee et al., 2020). Thus, the result of the testing is decrease as the number of processing oil increase.

Table 4.5.2: Hardness Shore A testing for rubber compound loading with TWCO and WCO.

Sample (PHR)	TWCO	WCO
0	66	66
5	62	62
10	56	60
20	54	58

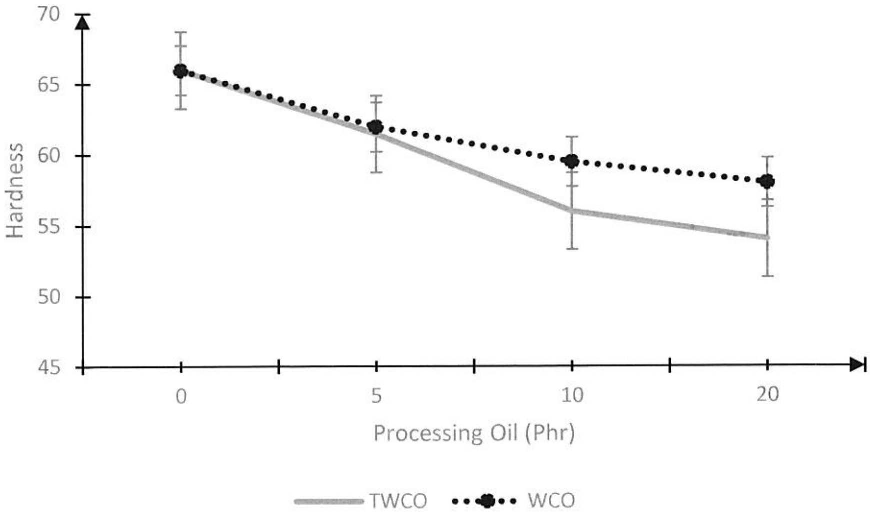


Figure 4.5.2: Hardness Shore A Testing for rubber compound loading with TWCO and WCO.

4.5.3 Specific Gravity

Specific gravity is ultize to identity an unknown substance and also to distiguish the sample (Mishra, 2005). Figure 4.5.3 show the specific gravity of rubber compound loaded with treated waste cooking oil and waste cooking oil. Based on the figure, it shows that as the number of processing oil is increasing, the value of specific gravity is decreasing. The control sample show the highest value of specific gravity. Meanwhile, the rubber compound which added with waste cooking oil of 20 phr has the lowest value of mooney viscosity. The control rubber compound result is 2.08% lower if compared to the rubber compound that loading with 20 phr of treated waste cooking oil. Mishra in 2005 also mention that processing oil or extender oil help the crosslinking process and resulting the reduction of specific gravity as the number phr of processing oil increased.

Table 4.5.3: Specific Gravity for rubber compound loading with TWCO and WCO.

Sample (PHR)	**TWCO**	**WCO**
0	**1.126**	**1.126**
5	1.122	1.121
10	1.107	1.113
20	1.103	1.109

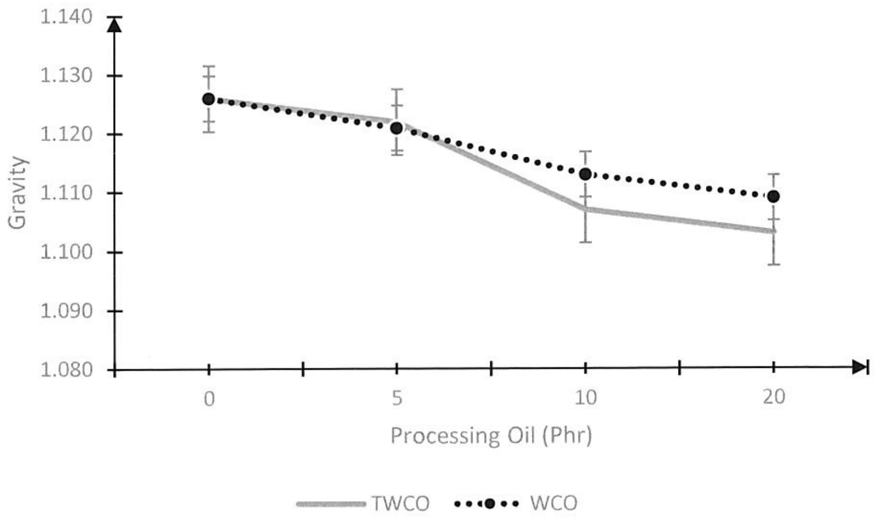


Figure 4.5.3: Specify Gravity for rubber compound loading with TWCO and WCO.

4.5.4 Density Analysis

Density is mass divided by volume (Norhazariah et al., 2016). Based Figure 4.5.4, generally the result show that the result of rubber compound which loaded with the processing oil is decreasing, as the amount of PO is increasing. However, when five phr of treated waste cooking oil is added to rubber compound, the density value is 9.04% higher than the control sample. The result of density for rubber compound with loaded with 10 phr of treated waste cooking oil is almost same as the rubber compound added with the waste cooking oil. If compared to the control sample, the value of max torque is around 3.05% lower. The value of density for rubber compound loaded with TWCO is lower due to the incorporating transesterification waste cooking oil which also has lower hydroxyl value. The reduction of the hydroxyl group cause the reduction of crosslinking during the vulcanization process (Arniza et al., 2015).

Table 4.5.4 Density Analysis's table for rubber compound loading with TWCO and WCO.

Sample (PHR)	TWCO			WCO		
	Mass (g)	Volume (mL)	Density (g/mL)	Mass (g)	Volume (mL)	Density (g/mL)
0	17.23	1.47	**11.72**	17.23	1.47	**11.72**
5	14.45	1.13	**12.78**	15.25	1.31	**11.64**
10	20.10	1.86	**10.80**	15.02	1.35	**11.13**
20	15.09	1.54	**9.79**	14.02	1.29	**10.86**

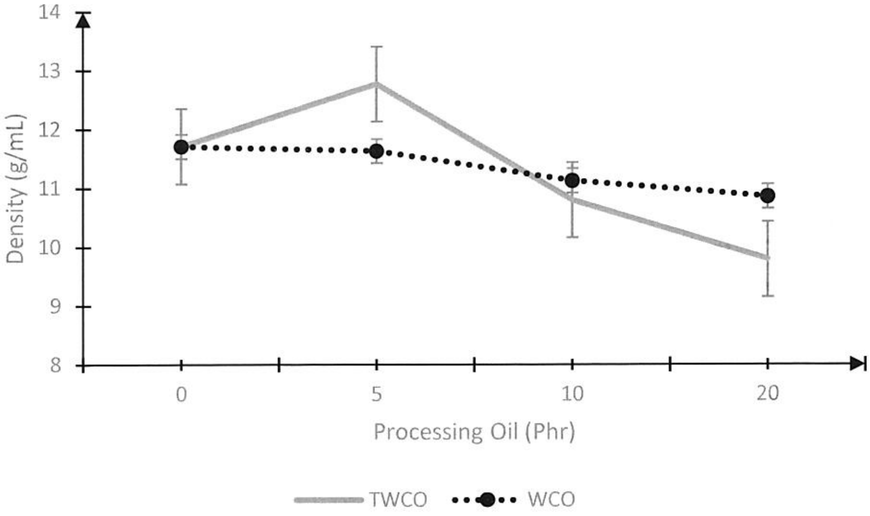


Figure 4.5.4: Density Analysis's conpararion of rubber compound loading with the TWCO and WCO.

4.6 Mechanical Testing

To understand the mechanical characteristic and properties of the rubber compound when added with processing oil, the mechanical testing is carried out. The three mechanical testing are the tensile testing, elongation at break and the 300% modulus.

4.6.1 Tensile Strength Testing

The definition of tensile strength is the max or highest mechanical stress when force is applied on the material (Masa et al., 2017). Figure 4.6.1 shows the tensile strength's result of waste cooking oil compared to the transesterification waste cooking oil. For the waste cooking oil, the result is decreasing as the number of processing oil added is increase. The tensile strength for the control sample is highest which is 28.8 Mpa. Meanwhile, the tensile strength result for transesterification waste cooking oil is slightly difference. The trend of result almost same with the waste cooking oil. At 5 phr of TWCO which added to the rubber compound, the result is significantly different if compared to the WCO result. This is due to the processing oil acts as the plasticizer and act as activator in vulcanizing system of the rubber compound (Li et al., 2016). It greatly enhancing the interface and improving the flexibility of the sample. Furthermore, it shows that lower tensile strength is caused by double bond in hydrocarbon chain which interact with curing agent and make it more complicated (Barlow, 2018).

When the tensile load is applied, significant interphase interaction will happen. This happen because the maximum stress point is reduced, it causes the mechanical strength to be improved. Generally, the processing oils that will soften the rubber is a plasticizer (Chanpon et al., 2014). It also predicted as the processing oil loading is increasing, the tensile strength would be decreasing.

Intermolecular interaction as well as cohesion, which both influence tensile strength in crystalline structures. When the processing oil is loading to the rubber compound, processing oil start to lubricate and help the plasticizer process. It reduces the internal force that exists between the rubber molecules (Boontawee et al., 2012). Thus, the processing oil fill the gaps of molecules easily and without hustle.

Table 4.6.1: Tensile Strength's Result of rubber compound loading with TWCO and WCO

Sample (PHR)	TWCO	WCO
0	28.8	28.8
5	21.5	27.5
10	26.7	26.8
20	25.0	24.0

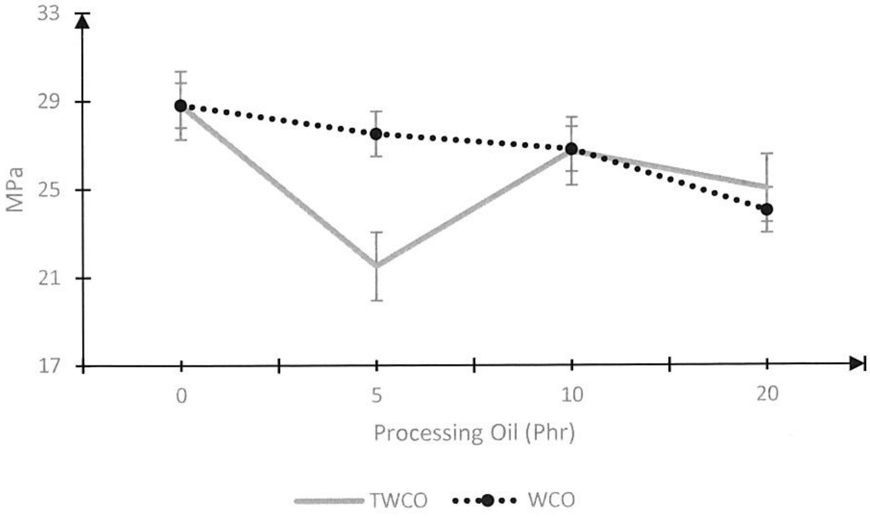


Figure 4.6.1: Tensile Strength's Result of rubber compound loading with TWCO and WCO.

4.6.2 Elongation at Break

Generally, the definition of elongation at break is used to evaluate the sample ductility (Kalkornsurapranee et al., 2018; I. Surya et al., 2017). Increased elongation at break is also due to the reduction in molecular interaction. The addition of oil in the rubber composite allows the rubber molecules to be stretched, or pushed apart as a consequence of the rubber will swelling (Syamin et al., 2017). Figure 4.6.2 shows that the sample which loading with waste cooking oil is steadily increasing as the loading amount is increased. The result of transesterification of waste cooking oil is different if compared to the waste cooking oil. The trends are still the same. At 10 phr of transesterification waste cooking oil is added to the rubber compound, it shows significantly different than the sample which added with WCO. However, at 20 phr of TWCO is added, the result is decrease to 598% of elongation at break.

This is posible due to the presence of the greater chain number which entangle with each other. The second theory that can be relate with this result is that upon the processing oil is added, it helps to reduce the intermolecular bond between the rubber chain. Thus, this can enhance the flexibility of the rubber compound and the chain. In addition, as the loading of processing oil is increasing, it showed that the stiffness is decreasing. This is due to the high concentrations of plasticizer (Siwarote et al., 2017). This could be attributed to presence of polar ester groups in bio-based oils. The result of lossing stiffness will cause a significant elongation at break when the load or force is applied.

Table 4.6.2: Elongation at Break for rubber compound loading with TWCO and WCO.

Sample (PHR)	**TWCO**	**WCO**
0	512	512
5	494	541
10	626	569
20	598	582

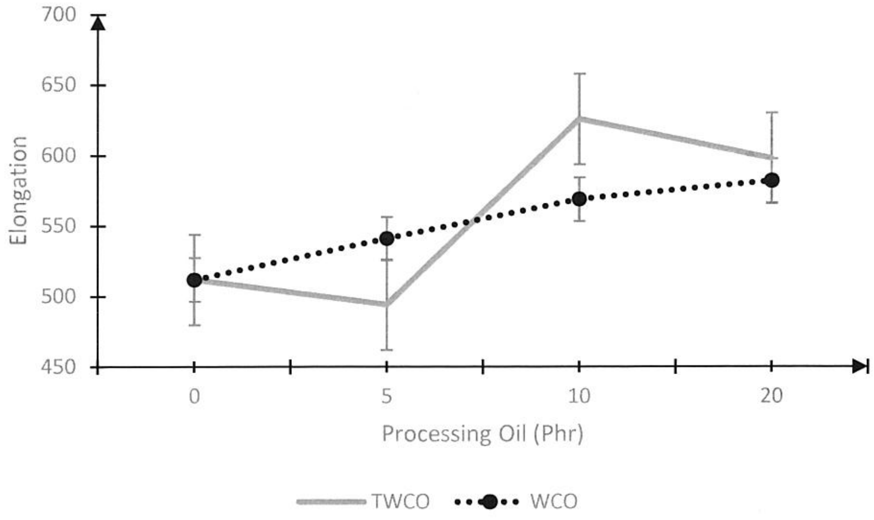


Figure 4.6.2: Elongation at Break of rubber compound loading with TWCO vs WCO.

4.6.3 The 300% Modulus

Modulus represents the resistance to extension or stiffness of the material (Wypych, 1998). The greater the high tensile modulus will signify that the samples are stiff. Thus, greater stress is necessary to achieve a satisfactory level of strain. This means that the sample or material resilient to deformed and being stretched. Alternatively, modulus is used to define the sample since modulus correlated to the stiffness. Then the tendency for the sample to resist the deformation when force is applied can be identify.

From the result, tranesterification waste cooking oil of 20 phr show the lowest value of young's modulus. Oppostion of the result is the control sample which has 0 phr of processing oil in it. This is due to the antiplasticization (Siwarote et al., 2017). Antiplasticization refer to a characterization which also a mechnical phenomena which cause by the amount of processing oil mixed with the rubber compound. Hence, this shows the result of processing oil's presense. Antiplasticization is caused when there are strong contacts involving plasticizer molecules as well as rubber chain molecules (Jayewardhana et al., 2009). This phenomenon is linked to a reduction in the amount of free volume present in the rubber chain.

Table 4.6.3: 300% Modulus for rubber compound loading with the TWCO and WCO.

Sample (PHR)	TWCO	WCO
0	15.9	15.9
5	11.2	12.7
10	9.1	11.0
20	8.9	10.0

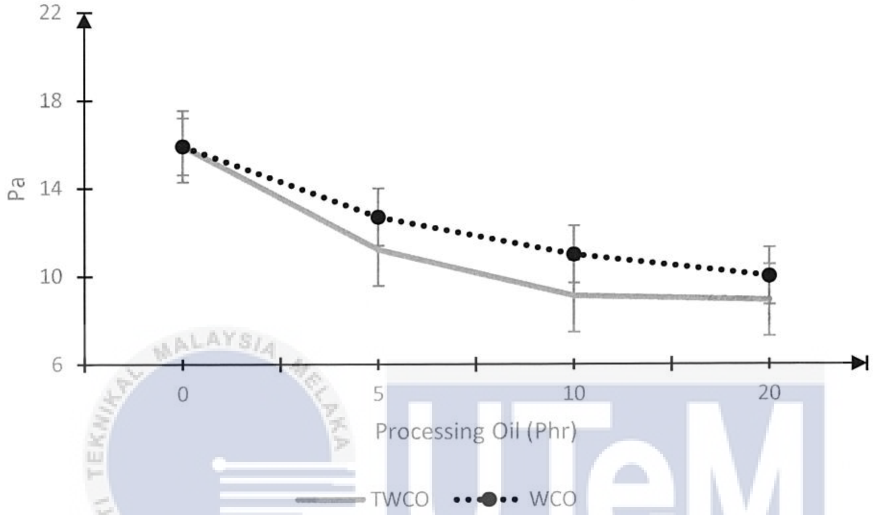


Figure 4.6.3: 300% Modulus for rubber compound loading with TWCO and WCO.

4.7 SEM Observation for Frature Morphology

For clearer characterization of the sample, the observation should be done by the SEM. Scanning Electron Microscopy is ultize on the characterization on rubber compound to determine the surface morphology of the rubber compound (Khairi et al., 2019).

However, due to coating machine in the lab is not available, thus the only option is Variable Pressure Scanning Electron Microscopy (VPSE). VPSE is one of the techniques to get the surface image for low conducticity sample and hydrated sample. The sample that been choosen to be observe by the SEM is control sample, 5 phr rubber compound loading with TWCO and 5 phr rubber compound loading with WCO.

SEM analysis is to relate the plasticiser effect of TWCO and WCO as processing oil on the facture morphology of natural rubber compound. Generally, the function of processing oil is to ease the introduction of chemical substance to the rubber compound. The image of control sample and 5 phr of WCO loading to the rubber compound are almost have similar.

It can been seen that the shearing mark on the rubber compound surface of WCO and TWCO on Figure 4.7.2 and Figure 4.7.2. Meanwhile the shearing mark for control sample is not obvious. Based on the previous research, the white dots that appeared on the image is identify as the carbon black particles (Koley et al., 2021). Due to the quality of image, it was not clear whether the processing oil helped in the dispersion of the filler or carbon black. Thus, future researcher should coating the sample first to fully get better quality of image.

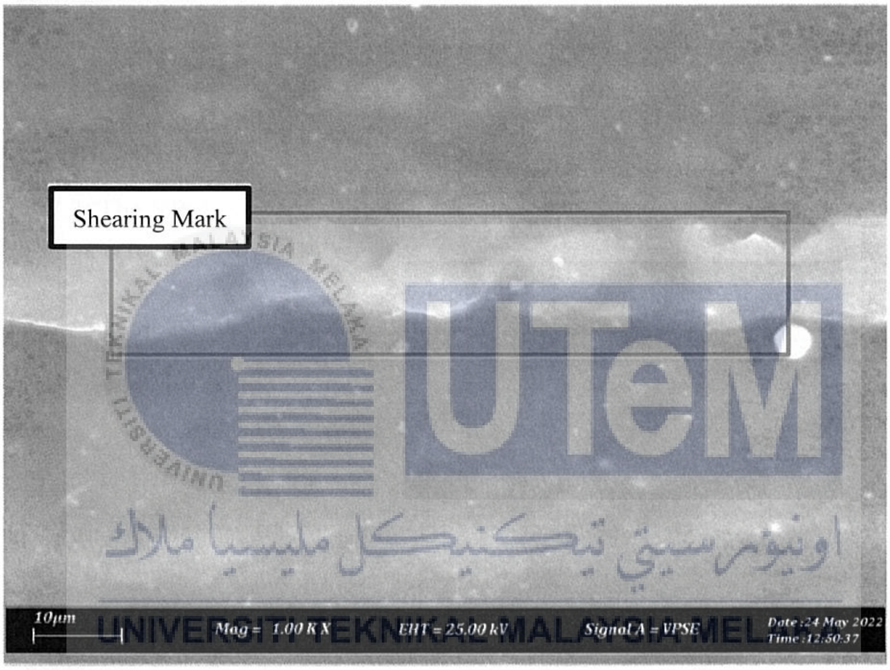


Figure 4.7.1: The VPSE's image of control sample for rubber compound.

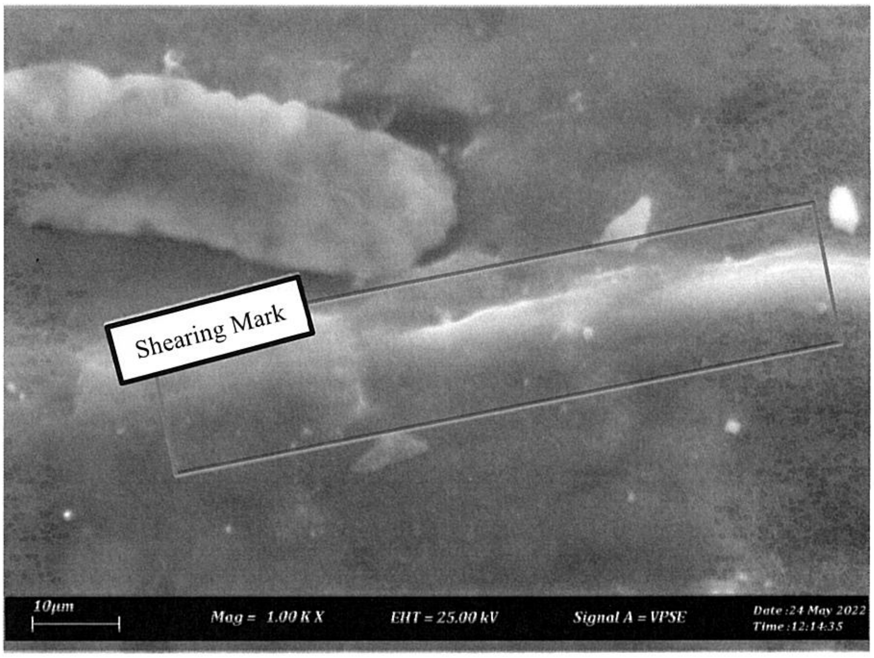


Figure 4.7.2: The VPSE's image of rubber compound loaded with WCO as processing oil.

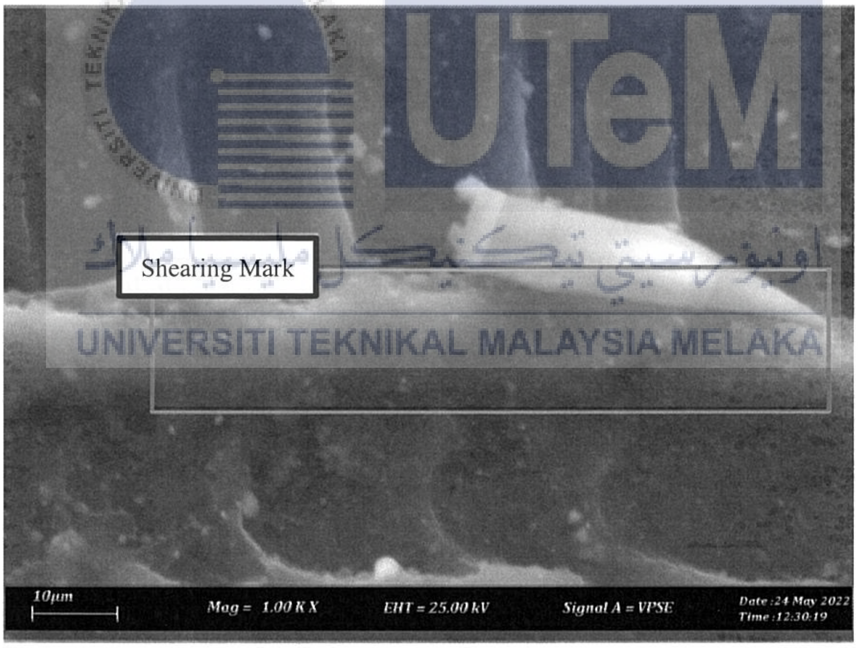


Figure 4.7.3: The VPSE's image of rubber compound loaded with TWCO as processing oil.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

This chapter had focused on the conclusion drawn from the discussion of the results in Chapter 4. Furthermore, this conclusion may be utilized to examine if the Chapter 1 goals are realizable. Recommendations are also presented in this chapter to offer ways to enhance the research's results, and the chapter concludes with a discussion on sustainability.

5.1 Conclusions

The first objective of this study to evaluate the effect of loading variation for two different types of processing oil via the oscillating cure rheometer is sucessfully achieved with some highlights as the followings.

I. Waste cooking oil is the raw material that was used in this research. The new candidates of transesterification as new processing oil for rubber compound were sucessfully suggested.

II. There are four sample which include control sample were produced with different loading of tranesterification waste cooking oil and waste cooking oil. The loading addition of processing oil are zero phr, five phr, ten phr and twenty phr.

III. It has seen that through result of cure characteristic analysis, density testing and mooney viscosity, the rubber compound which loaded with WCO as processing oil comparable to the TWCO.

IV. The appearance of both processing oil also comparable. The appearance of WCO is vicous fluid and brown color. Meanwhile, the appearance of the TWCO is liquid and yellowish in color. The value of dynamic viscosity of WCO is higher than the TWCO which is 0.012 poise and 0.06 poise respectively.

The second objective of this research is to determine the effect of different loading addition of processing oil to the mechanical and physical properties of natural rubber compound by using various related testing is successfully achieved. The following significant finding that indicates fulfillment of the second aim is provided as follows.

I. In this study, the result of shore A hardness and specific gravity with 20 phr of TWCO as loading processing oil indicate the lowest among other samples, which are 54 and 1.103 kg/m3.

II. The rubber compounds with 5 phr loading addition of TWCO processing oils is the lowest tensile strength and elongation at break among other samples which are 21.5 Mpa and 494 %.

III. For the 300% modulus, the rubber compound that loading addition with higher number phr of processing oil shows the lowest value of 300% modulus. However, the value of 300% modulus for transesterification waste cooking oil shows lower value if compared to rubber compound loaded with waste cooking oil as processing oil.

IV. As the alternative of the aromatic processing oil in the rubber compound, TWCO and WCO can be used. However, the result of rubber compound that ultise the TWCO as processing oil shows better result and more effective if compared to WCO. This is due to the TWCO is a better vulcanizing system activitor for rubber compound.

The third objective is to relate the plasticiser effects of green processing oil addition with the fracture morphology of natural rubber-based compounds through the Scanning Electron Microscope (SEM) observation.

I. The coating machine in the lab is not available, thus the only option is Variable

Pressure Scanning Electron Microscopy (VPSE). VPSE is one of the techniques to get the surface image for low conducticity sample and hydrated sample.

II. The sample that been choosen to be observe by the SEM is control sample, 5 phr rubber compound loading with TWCO and 5 phr rubber compound loading with WCO.

III. The image of control sample and 5 phr of WCO loading to the rubber compound are almost have similar.

As a result of a huge breakthrough and the greatest potential of this research towards a greener as well as safer environment, this work is deemed honourable in terms of conserving the environment for future generations.

5.2 Recommendations

Based on the result of the study, there are fews recommendations that maybe used in the future. Among all are as follows:

I. The aromatic or paraffinic oil should be included and use in this study. Thus, a better comparation of result can be done between the waste cooking oil and the transesterification waste cooking oil.

II. Selecting a better and more optimum parameter for preparing the transesterificaction waste cooking oil can be option to add on in the future.

III. The application of the TWCO and WCO as processing oil in the rubber compound should be done again in the future by collab with related industry. Thus, a better result will be obtained due to the implementation of the processing oil in the indusrty based on the real and actual industry situation.

IV. In order to identify that the transesterifaication waste cooking oil is successful, the researcher should be focus on the presence of hydroxyl group which is ester and the vanishing of the C=C bond.

5.3 Sustainability Element

There are several sustainable developments that had been discovered through this study which make the manufacturing cost of rubber product can be reduced. As mentioned before, this study is utilized the waste cooking oil. Thus, humankind will be on advantage if we can ultized this waste cooking oil.

The other advantage of utilizing this waste via tranesterification, it can transform the waste into biodiesel. Futhermore, waste cooking oil and transesterification can be suitable candidate of processing oil for rubber compound. If the waste such as cooking oil can be utilize, this will be great potential for preserving the society and the enviroment.

Futhurmore, this study also provides solutions of waste which can be included in the recycling businesses. Thus, this idea will be changing the waste into the profit and wealth. In addition, it is one of the methods that can be implemented to solve the problem of waste cooking oil disposal by regulating the use of waste resources in order to preserve the ecological balance.

5.4 Lifelong Learning Element

Transesterification process has a lot of advantage on the waste cooking oil. From this study, show that the TWCO are able to be ultise as the processing oil. However, the TWCO has other posibble applications. Transesterification of waste cooking oil can be use as the biodiesel. As we know, the price of petrol and diesel is soaring up due to the shortage of supply and the effect of Ukraine-Russia's conflict. By identify the optimum parameter of preparing the transesterification waste cooking oil would be advantage and more confident for the industry to utilize this waste as the fuel to the transportation.

If this study can be applied on the related industry in the future, the cost of making rubber compound's product can be reduced and accomplished. Currently, the utilization of the non-renewable energy such as crude oil cause the product's cost drastically increased. This is also due to the depletion of the natural energy resources. Thus, by using the waste cooking oil as the processing oil will reduced the cost.

5.5 Complexity Element

In this study, the complexity may be found while doing the tranesterification process of waste cooking oil. Since the exact or optimum chemical that should be mix with the waste cooking oil is not widely researched. As we know, the measurement of every raw material and chemical should be precise in order to optimise the characteristics of the products.

Futhurmore, the suitable number of phr for processing oil loaded to the rubber compound is still cannot be validated since this result of this study is still general. In order to be more specific and scientific, the researcher should compare this WCO and TWCO with the common processing oil that available on the market. Thus, the result would be more significant.

In addititon, there are maybe few limitations might when conduct the study. Based on this study, there ara limitation in times and lack of proper material or chemical substance. Thus, the collaboration with the related company should be make the progress of such study faster and benificial to both parties.

5.6 Basic Entrepreneurship (BE)

Nowsday, a lot of things that happen on the world. Turning waste into a business is one of good way to help earth to recover. From this study, it shown that the waste cooking oil and transesterification waste cooking oil can be use as the processing oil for the rubber compound. The rubber industry can add these green processing oils as their options without only relies on the aromatic and paraffinic processing oil. It also has shown in mutiple research that the waste cooking oil is non-toxic to humankind. Thus, the rubber industry can be reducing a lot of money if they choose to utilize this waste as their processing oil.

This study is very good for the business opportunity. The reason is due to the preparing waste cooking oil has few steps which probably make the rubber industry try to avoid it and save their time of operation. Therefore, collecting and filtration of waste cooking oil can be one of business opportunity. With the right price, pretty sure the industry will grab the ready to use waste cooking oil.

For the transesterification waste cooking oil, this waste can be use in other applications. This treated waste is also known as the biodiesel, which also mean it can fuel the vehicle. The fossil petroleum is not renewable energy thus, this transesterification oil can be use as the fuel. Further study of this transesterification oil would be advantage to the humankind. Introducing this as the other option of fuel would be a substantial fortune to the entrepreneur. As we know, the world is in transition of using the electric vehicle. But if this type of oil can be use, we can help to save the world and reduce the waste of cooking oil on the same time. Together we will make the world better place in the future.

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Appendix