EFFECTS OF PYROLYSIS BIO-OIL FROM PALM KERNEL SHELL ON BITUMEN PROPERTIES

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FACULTY OF ENGINEERING
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2022

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THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF BACHELOR OF ENGINEERING (CIVIL ENGINEERING)

FACULTY OF ENGINEERING
UNIVERSITI MALAYSIA SABAH
2022

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ACKNOWLEDGEMENT

First and foremost, I would like to thank and praise Allah SWT for the blessings by His willingness throughout my study for Final Year Project which I am able to conduct successfully.

Secondly, I would like to express my utmost gratitude to my supervisor, Ts. Dr. Lillian Gungat for granting my request to be one of her final year project students. I am fortunate to be blessed with the opportunity to conduct my research under her supervision and she have been continuously giving me support, guidance and unlimited encouragement that helped me all the time. Without her guidance and patience, I would not have come this far.

Additionally, I am thoroughly grateful to my family, my mother Rozilah Binti Borhan and my father Abdul Manan Bin Abdul Rasit, as well as my two older sisters Nur Amaleena and Nur Amaleeza, for their outstanding support, love, encouragement, and care for the sake of my education and future attributes. Thank you for everything you have done to me. I will repay all sacrifices and kindness to you in the future.

Last but not least, special thanks to my ultimate circle, Hanni Morisha Binti Moktar, Nurdini Atiqah Binti Talib, Ak Muhammad Saufi Bin Ak Ali Putra, and Muhammad Muizzuddin bin Mukhtar, who have been there for cheering me up with continuous and tremendous supports they had given as well as correcting me when I am making mistakes despite having the same hurdles just like me throughout the completion of this project. I have nothing to say other than saying thank you to all of you. Without you guys, I may not be able to fully enjoy my university life. I hope that the same energy and kindness will return to you guys and I hope all of us will be success in the future.

Thank you very much.

Nur Afeera Syakirin Binti Abdul Manan
20 July 2022

ABSTRACT

Sustainability and economy are the significant elements that must be considered in all fields and sectors, including the road sectors in this growing and developing nation. One alternative that can possibly achieve the sustainable and economical aspects in the road industry is by the application of sustainable pavement materials such as bitumen with renewable materials. Therefore, research on the renewable materials such as bio-oils that are obtained through pyrolysis from the local palm oil industries were conducted. Despite bio-oils improve the properties of bitumen for several researches in the existing literature reviews, the study on the effects of PKS bio-oil to bitumen properties is still limited. The objective of this study is to investigate the effects of palm kernel shell (PKS) bio-oil to the physical properties, the chemical functional group, and the morphology of the bio-oil modified bitumen. PKS bio-oil was incorporated into the bitumen by weight of bitumen at 2%, 3%, 5%, 10%, 15%, and 20% of PKS bio-oil. Bitumen modified with PKS bio-oil was compared with the control bitumen 60/70 that is commonly used as pavement in the industry. From the conventional physical test of PKS bio-oil modified bitumen, it was found that the penetration increases, softening point decreases, and the ductility increases with the addition of PKS bio-oil. For example, at 2% of PKS bio-oil modified bitumen, the penetration of the modified bitumen is found at 75dmm, in which the softening point is 46°C, and the ductility is 142cm. Therefore, the physical properties test showed that the softer grade bitumen is achieved as the PKS bio-oil content increases. The functional group of bitumen which consists of carbonyl, sulfoxide, esters, aliphatic and aromatic structures are indicated through IR spectrum by the Fourier Transform Infrared Spectroscopy (FTIR) analysis and the change of the functional group is significantly influenced by the increasing content of bio-oil. From the images produced by the Scanning Electron Microscopy (SEM) analysis, the morphology of the modified bitumen with respect to the conventional control bitumen are clearly indicated that modification effect existed. Consequently, PKS bio-oil can be used as a replacement of bitumen in the region which is prone to have low temperature, hence the soften grade bitumen achieved for the bio-oil modified bitumen are able to slower down the hardening rate of the bitumen.

ABSTRAK

KESAN PENGGUNAAN PIROLISIS BIO-MINYAK DARIPADA KERANGKANG BIJI KELAPA SAWIT TERHADAP CIRI-CIRI KHAS BITUMEN

Kelestarian dan ekonomi adalah dua unsur yang penting dan perlu dititikberatkan dalam semua bidang dan sektor, termasuklah sektor jalan raya yang semakin berkembang di negara ini. Salah satu alternatif yang dapat dilaksanakan untuk mencapai unsur kelestarian dan ekonomi adalah dengan cara pengaplikasian bahan turapan yang mampan seperti penyampuran bio-minyak dalam bitumen. Oleh itu, kajian mengenai bahan yang boleh diperbaharui seperti bio-minyak daripada sisa organik yang diperoleh melalui pirolisis daripada industri minyak sawit tempatan telah dijalankan. Walaupun bio-minyak terbukti meningkatkan sifat bitumen dalam beberapa kajian dan tinjauan literatur sedia ada, kajian tentang kesan bio-minyak PKS terhadap sifat bitumen masih terhad. Objektif kajian ini adalah untuk menyiasat kesan bio-minyak daripada kerangkang biji kelapa sawit (PKS) kepada sifat-sifat fizikal, kumpulan berfungsi kimia, dan morfologi bitumen yang telah diubahsuai dengan bio-minyak PKS. Bio-minyak PKS digunakan ke dalam bitumen dengan peratusan 2%, 3%, 5%, 10%, 15%, dan 20% dengan berat bitumen dan telah dibandingkan bersama bitumen tulen dengan gred penembusan 60/70. Daripada ujian bitumen yang telah dijalankan, penembusan bitumen meningkat, titik lembut berkurang, serta kemuluran bitumen bertambah dengan penambahan bio-minyak PKS ke dalam bitumen. Sebagai contoh, pada bitumen yang dimodifikasi dengan 2% bio-miyak PKS, ujian penembusan yang dijalankan menunjukkan kedalaman sebanyak 75dmm, dan titik lembut pada suhu 46 darjah Celsius, serta kemuluran 142cm. Oleh yang demikian, ujian fizikal bitumen ini menunjukkan bitumen begred lembut telah dicapai dengan peningkatan bio-minyak PKS ke dalam bitumen. Kumpulan fungsi kimia bitumen yang terdiri daripada struktur karbonil, sulfoksida, ester, alifatik dan aromatik direpresentasikan daripada spektrum inframerah yang diperoleh daripada ujian FTIR. Perubahan kumpulan fungsi kimia ini mempunyai hubungan adalah dipengaruhi oleh kandungan bio-minyak yang semakin meningkat. Daripada gambar yang diperoleh daripada analisis SEM, morfologi bitumen yang sudah diubahsuai telah menunjukkan kesan yang jelas terhadap pengubahsuaian yang telah dilakukan. Sebagai kesimpulan, bio-minyak PKS boleh digunakan sebagai pengganti bitumen di kawasan yang terdedah kepada suhu yang rendah, justeru bitumen gred lembut yang dicapai mampu memperlahankan kadar pengerasan bitumen.

LIST OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PHOTOS

LIST OF SYMBOLS

Σ	-	Summation
±	-	Plus-minus
T_{pyr}	-	Pyrolysis Temperature
$T_{heating}$	-	Heating Time for Fuel
t_t	-	Pyrolysis Reaction Time
cP	-	Poise Unit
G*	-	Complex Unit
sin	-	Sin
δ	-	Phase Angle
rpm	-	Revolution Per Minute
I_a	-	Functional Group Index

LIST OF ABBREVIATIONS

AASHTO	-	American Association of State Highway and Transportation Materials
ASTM	-	American Society for Testing and Materials
BBR	-	Bending Beam Rheometer
BioCS	-	Pyrolysis Coconut Shell
CSC	-	Coconut Shell Charcoal
DSR	-	Dynamic Shear Rheometer
EDX	-	Energy Dispersive X-Ray
EFB	-	Empty Fruit Bunches
FA	-	Foamed Asphalt
FTIR	-	Fourier Transform Infrared Spectrometer
GHG	-	Greenhouse Gas
MDI	-	2,4-diphenylmethane diisocyanate
OPF	-	Oil-Palm Fronds
OPMF	-	Oil-Palm Mesocarp Fibre
OPT	-	Oil-Palm Trunks
PI	-	Penetration Index
PKO-p	-	Palm Kernel Oil-based Monoester Polyol
PKS	-	Palm Kernel Shell
PMA	-	Polymer Modified Asphalt
POME	-	Palm-oil Mill Effluent
PVN	-	Penetration Value
RA	-	Rubberized Asphalt
RAP	-	Reclaimed Asphalt Pavement
RTFO	-	Rolling Thin Film Oven
RV	-	Rotational Viscometer
SDG	-	Sustainable Development Goal
SEA	-	Sulfur-Extended Asphalt
SEM	-	Scanning Electron Microscopy
TGA	-	Thermo-gravimetric Analysis

TSR	-	Tensile Strength Ratio
WCED	-	World Commission of Environment and Development
WCO	-	Waste Cooking Oil
WMA	-	Warm Mix Asphalt

CHAPTER 1

INTRODUCTION

1.1 Background of Study

In this day and age, sustainability in every aspect of life is one of the essential considerations to meet the basic human needs without discarding the future generation's life and well-being as defined by World Commission of Environment and Development (WCED) (Plati, 2019). Sustainability in road industry must have the feasibility to utilize resources effectively and conserve the ecosystems in the environment. These days, sustainability and economy are two principal elements that must be implemented in all industry sectors which includes the building and construction sectors (Zavadskas et al., 2018).

Road sectors are part of the construction industry, which had contributed to the depletion of natural resources and led to critical damage to the environment. Despite the extreme threats it had caused, it is undeniable that the construction of roads cannot be limited in its implementation as it holds the responsibility to assist the development of the country. Thus, it is significant to minimize the use of natural resources as a way to provide sustainable aspect as well as preserving the structural integrity.

A particular way to make it possible is to apply the highway construction materials such as bitumen with renewable materials and to reduce the reliance on consuming non-renewable resources that will eventually results in the emission of greenhouse gas (Ingrassia et al., 2020). In this case, the utilization of renewable materials that are by-products of industrial activities or even regular output in daily life may be adopted as an additive to the bitumen. According to Kumar et al. (2020), modification of the bitumen had become an interesting topic that researchers had

been concentrating on as well as the strength and durability of the modified bitumen are evaluated and examined. This is done to ensure that the modification of bitumen has better strength and durability without any environmental impact as it did with the conventional bitumen.

Moreover, bitumen modification will also contribute to the economical aspect where a considerable costs cutback is possible by using bio-materials as additives in bitumen, thus enhancing the bitumen properties for performance improvement in road application (Kumar et al., 2020). Bio-materials have become one of the most desired sources for its renewable characteristic and possess lower price as the bio-materials are produced by the local industry, environmentally friendly, and have comparable less energy consumption to the petroleum-based materials (Al-Sabaeei et al., 2019). Additionally, bio-materials as an alternative green technology have become one of the major areas of interest to be implemented which comprehends a better and sustainable design, construction, and maintenance of pavement in the industry (Al-Sabaeei et al., 2019). An example of the bio-materials application in pavement is the construction of roads in Norway in the year of 2007, where vegetable oil is utilized (Su et al., 2018; Al-Sabaeei et al., 2019). Bio-material which is often used as the subject for research purpose and potentially used in pavement is bio-oil, which is often termed as bio-binder.

Bio-oil is usually extracted from waste and organic resources which have gone through a sequence of physical and chemical process, namely fast pyrolysis technology that is involved with thermochemical technologies. This technology is capable in transforming biomass waste from various sources, such as corn stover, waste rose pulp, wood, soybean oil, palm kernel polyol, coconut shell, charcoal ash coconut oil, and waste cooking oil into many useful energy forms which are bio-oil, biochar, and biogas. To convert these biomass wastes into the mentioned energy forms, pyrolysis processes are primarily categorized into both slow pyrolysis and fast pyrolysis (Bala et al., 2018). Fast pyrolysis is often carried out to maximize the formation of liquid or bio-oil in which it is handled and operated at moderate high temperature and optimum atmospheric pressure (Leng et al., 2018).

The production of bio-oil is eventually having the prospective to replace the conventional binder that it significantly gives way to sustainability and environmental

protection (Leng et al., 2018). Compared to typical fossil fuels, bio-oil is environmentally friendly and renewable that it is energy intensive and carbon neutral (Leng et al., 2018). One of the bitumen properties that is often considered important is viscosity. A study had suggested that bio-oil has high moisture content which results in the low viscosity of the liquids that is not quite desirable for bitumen, hence the behavior of the bio-oil during pyrolysis must be controlled so it does not influence the physical properties of the liquid produced which will in time affect the behavior of the bitumen (Poh et al., 2018). Additionally, bio-oil is capable to be used in the context of bitumen modification to give solution to demand in petroleum-based binders. The suggested ways of applying bio-oils to bitumen are bio-oil can act as a bitumen modifier with bitumen replacement is less than 10%, bitumen extender with bitumen replacement is in range of 25% and 75%, and as an alternative binder in which the bitumen is wholly replaced with bio-oils (Alamawi et al., 2019). Nevertheless, most of material researchers have proposed the bio-oil as a modifier into the asphalt and analyzed the performance of bio-modified asphalt or bitumen.

Many researchers had concluded that bio-oil has excellence properties that it could be used as a binder in the road construction or even replace the bitumen completely, where most of them are significantly being assertive that the bio-oil can possibly be implemented, thus gives reason on the increasing number of studies and researches of bio-oil and bio-asphalt recently (Wang et al., 2020). Most researchers had performed substantial tasks on exploring the production technology and properties of various bio-binders and the performance of each in the asphalt mixtures which consist of bio-binders (Su et al., 2018). However, there is a gap in evaluating the performance of modified bitumen with the bio-oil from the palm oil industry, particularly the palm kernel shell (PKS) resource. Therefore, this research focuses on the modification of bitumen mixed with a by-product of PKS which is then converted and transformed into bio-oil.

1.2 Problem Statement

In the arising development of road in the country, it is undeniable that there is a progressive reduction of natural resources such as fossil and petroleum resources which corresponds to the active decline in the environment condition and caused a drastic change in the climate condition. The growing demand for petroleum products, such as bituminous binder, has diminished the petroleum reserves as well as increasing the energy and operation cost. Due to this problem, the construction of road has faced the growing cost of the petroleum by-products (Alamawi et al., 2019). Besides, as there are ongoing effects on the environment as the increase usage of the petroleum product, there have been some effective attempts in the sustainable and renewable energy resources hunt by several researchers to alleviate the limitations and downside of fossil fuels, but these efforts have yet to have any significant effect on turnout. As studied by Terzi et al. (2020), several solutions to this matter are by performing bitumen modification, aggregate replacement or by using additives into the bitumen mixtures. The bitumen modification is utilized by applying bio-materials such as bio-oil to the bitumen.

Despite bio-oils improve the properties of bitumen for several researches in the existing literature reviews, the study on the effects of PKS bio-oil to bitumen properties is still limited. Research on the effect of PKS bio-oil for bitumen replacement is limited on the bitumen properties such as penetration, softening point, and ductility. Additionally, the in-depth test through chemical test is not often studied upon the bitumen modification using bio-materials as have been researched by Alamawi et al. (2019) and Ingrassia et al. (2020). Besides, although the morphological of modified bitumen is often conducted to study the change in bitumen microscopy, there is limited study for the bitumen modified by PKS bio-oil. Therefore, this study is conducted to determine the properties of the bio-oil modified bitumen through a laboratory work, and chemical analysis by using Fourier Transform Infrared Spectroscopy (FTIR) which determines the effect of bio-oil modified bitumen to the functional group of the bitumen. This research also comprehends the morphological test to study the change in the form of bitumen by using Scanning Electron Microscopy (SEM) test.

1.3 Objectives of Study

This study investigates the effect of pyrolysis bio-oil from palm kernel shell to the properties of bitumen by using laboratory work. The primary objectives of this research are:

1. to investigate the physical properties of the modified bitumen with various percentages of bio-oil from palm kernel shell.
2. to determine the effect of functional group of the bio-oil based modified bitumen through Fourier Transform Infrared Spectroscopy (FTIR) test.
3. to examine the morphology of the modified bitumen subjected to different percentages of bio-oil by Scanning Electron Microscopy (SEM).

1.4 Scope of Study

This study is mainly circulated on the analysis and investigation of the bitumen properties as it transformed into modified bitumen by the utilization of the bio-oil from PKS as bitumen replacement. This study focused on the effect to the physical properties using penetration, softening point, and ductility tests. The chemical structure of the bitumen is also observed upon the modification of the bitumen. Additionally, the morphological form of the modified bitumen is studied. The study used the increment of percentages from 0%, 2%, 3%, 5%, 10%, 15% and 20% of bio-oil respectively to determine the characteristics affecting the performance of the bitumen. The source of bio-oil is originated from PKS which is obtained from local palm oil industry in Lahad Datu, Sabah. The bio-oil is already processed by a pyrolysis technology and the collected bio-oil is used as samples for the laboratory research. The method used to blend the bio-oil and bitumen is by using the high speed of 500rpm mechanical stirrer within 25 minutes in a maintained temperature. The conventional tests of bitumen properties used by will be explained further in the methodology section.

1.5 Significance of Study

Conventional bitumen of various standard penetration grades is common in the application of road pavements, especially for flexible pavements. In this day and age, the employment of bio-oils as a replacement for fossil fuels is finite and there are inadequate studies to review the practicability and potential of bio-oils to act as bitumen modifiers. This research helps to show the improvement of the existing bitumen by binding with the bio-oils produced from PKS obtained from by pyrolysis technology. The findings of this study will significantly benefit the road industry in the utilization of bio-binders to be in line with the increasing demand for petroleum products particularly in Sabah.

The percentages of bio-oils proposed in this study may be potentially applied to determine the bitumen properties which met the same requirement as the common bitumen used in road pavements, not only Malaysia but other countries relevant to the outcome of this study. Sabah is reported to take the lead in palm oil industry with 40% of the smallholders of palm oil is coming from the 53,00 smallholders in Sabah (Wilson et al., 2018). By implementing the palm oil-based modified bitumen which will increase the market demand and employability opportunities towards the growth in palm oil industry in Sabah, the household income of the smallholders will increase to more than one third of their current incomes (Wilson et al., 2018). In other words, this study gives way to meet the sustainable economic and environmental development of using bio-oils in bitumen mix instead of the contemporary method.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

In this chapter, the origin of the bio-oil production will be thoroughly explained. The introduction of biomass wastes as the source of bio-oil will be given a comprehensive review. The primary review will be focusing on the employment of bio-oil to the bitumen which gives significant influences on the quality of the bitumen. This chapter will primely discuss the bitumen modification to convey better constructive findings. As a way of such modification, the bio-oil as an additive and/or replacement to bitumen, percentages applied to bitumen, as well as its effects to bitumen are further explored.

Moreover, this study comprehend in-depth understanding on how the bio-oil gives impact on the softening point, penetration, ductility and other properties of bitumen. As this study is primarily concentrating on the usage of PKSs, analysis of the background of this biomass and its properties are described. This study scrutinizes several principal reviews as in the following; 1. Bioresource and Waste Management Technology; 2. Pyrolysis Bio-Oil; 3. Modification of Bitumen Using Bio-Oil; 4. Effects of Bio-Oil on Bitumen Properties; 5. Chemical Test of Bio-Oil Modified Bitumen; 6. Morphology of Bio-Oil Modified Bitumen; and the summary of the literature review of this study. This chapter is completed upon the investigation and research through past studies published by relevant publications and authors.