BITUMEN MODIFICATION USING OIL PALM FRUIT ASH FOR STONE MASTIC ASPHALT

GATOT RUSBINTARDJO

UNIVERSITI TEKNOLOGI MALAYSIA

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GATOT RUSBINTARDJO

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“I dedicated this thesis to the knowledge of highway engineering as my worship to Allah Subhana wa Ta’ala

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ABSTRACT

The objective of this study was to investigate the feasibility of using oil palm fruit ash (OPFA) as a bitumen modifier, to formulate the mix between OPFA and bitumen as a new binder with better physical and mechanical properties, and to evaluate the use of OPFA-modified bitumen (OPFA-MB) as a binder of stone mastic asphalt (SMA). In this study two sources of bitumen, bitumen B-1 and bitumen B-2 each had penetration grade 80/100 were modified by using OPFA. The bitumen was mixed with 2.5%, 5%, 7.5%, 10%, 12.5%, and 15% OPFA by weight of the bitumen at mixing temperature 160°C, mixing time 60 minutes, and mixing stirring speed 800 revolution per minute. There were two types of OPFA, Fine and Coarse-OPFA. Fine-OPFA was OPFA which had uniform particle size 75µm, and Coarse-OPFA was OPFA which had graded particle with maximum grains size 600µm. The bitumen mixed with OPFA was called OPFA-modified bitumen (OPFA-MB). There were four types of OPFA-MB namely Fine-OPFA-MB1, Coarse-OPFA-MB1, Fine-OPFA-MB2, and Coarse-OPFA-MB2. Each type of OPFA-MB had six OPFA content. For all of OPFA-MB penetration test at 25°C, softening point test, and viscosity test at 60°C and 135°C were conducted to determine penetration index (PI) and penetration-viscosity number (PVN). The results show that all OPFA-MB were not susceptible to the changes of temperature. Rheology test using dynamic shear rheometer (DSR), bending beam rheometer (BBR), and direct tension tester (DTT) show that OPFA-MB with the content of fine-OPFA 5%, 2, 5%, and 10% can withstand rutting at a temperature of 70°C, withstand fatigue cracking at a temperature of 20°C, and resist to thermal cracking at a temperature of -15°C. Using in stone mastic asphalt (SMA-14) mixtures resulted in higher Marshall stability than the minimum specification requirements. Resilient modulus, creep, and wheel tracking rutting tests show that OPFA-MB can strengthen SMA-14 mixtures. Static immersion test, boiling water and drain-down test show that OPFA-MB has good adhesion to bind aggregate. Based on penetration value and the results of rheology testing, OPFA-MB can be categorized as binder penetration grade 60/700 and Superpave bitumen grade PG 70 – 16. Overall test results suggest that OPFA is feasible to be used as modifier of the bitumen, and as a binder for stone mastic asphalt.

ABSTRAK

Tujuan kajian ini adalah untuk mengetahui kesesuaian penggunaan abu buah kelapa sawit (OPFA) sebagai pengubah asfalt, untuk menentukan campuran antara OPFA dan asfalt sebagai bahan pengikat baru dengan sifat fizikal dan mekanik yang lebih baik, dan untuk menilai penggunaan OPFA-diubah bitumen (OPFA-MB) sebagai bahan pengikat *stone mastic asphalt*' (SMA). Dalam kajian dua sumber asfalt, asfalt B-1 dan asfalt B-2 masing-masing mempunyai tahap penusukan 80/100 yang diubahsuai dengan menggunakan OPFA. Asfalt dicampur dengan OPFA sebanyak 2.5%, 5%, 7,5%, 10%, 12.5%, dan 15% dari berat asfalt pada suhu pencampuran 160°C, selama 60 minit dengan kelajuan 800 revolusi per minit. Dua jenis OPFA, iaitu OPFA halus dan OPFA kasar digunakan. OPFA halus adalah OPFA yang mempunyai saiz 75µm, dan OPFA kasar adalah OPFA yang mempunyai dengan saiz maksimum 600µm. Campuran antara asfalt dan OPFA disebut OPFA-diubah bitumen (OPFA-MB). Ada empat jenis OPFA-MB iaitu OPFA-MB1 halus, OPFA-MB1 kasar, OPFA-MB2 halus, dan OPFA-MB2 kasar. Untuk semua uji penusukan OPFA-MB pada 25°C titik uji, dan uji kelikatan pada 60°C dan 135°C dilakukan untuk menentukan indeks penusukan (PI) dan nombor penusukan-kelikatan (PVN). Keputusan kajian menunjukkan bahawa semua OPFA-MB tidak sensitif kepada perubahan suhu. Ujian reologi menggunakan alat *Dynamic Shear Rheometer* (DSR), *Bending Beam Rheometer* (BBR), dan *Direct Tension Tester* (DTT) menunjukkan bahawa OPFA-MB dapat menahan alur yang didapati pada suhu 70°C, menahan keretakan lesu pada suhu 20°C , dan tahan terhadap *thermal cracking* pada suhu -15°C, untuk OPFA-MB dengan OPFA 5%, 2,5%, dan 10%. Digunakan sebagai bahan pengikat dalam campuran *stone mastic asphalt* (SMA)-14, semua campuran memiliki kestabilan Marshall melebihi spesifikasi. Keputusan dari uji kaji *Resilient modulus*, *creep*, dan *wheel tracking rutting*, menunjukkan bahawa OPFA-MB dapat memperkuat campuran SMA-14. Uji perendaman statik, uji air mendidih dan uji *downdrain* menunjukan bahawa OPFA-MB mempunyai pelekatan yang baik untuk mengikat agregat. Berdasarkan kepada nilai ujian penusukan dan ujian reologi, OPFA-MB boleh dikategorikan sebagai bitumen gred 60/70 dan bitumen gred PG 70 – 16. Secara keseluruhan hasil ujian menunjukkan bahawa OPFA sesuai untuk digunakan sebagai pengubah asfalt, dan sebagai bahan pengikat SMA.

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LIST OF SYMBOLS AND ABBREVIATION

ASTM	-	American Society for Testing Material
BBR	-	Bending Beam Rheometer
C	-	Celsius, Centigrade
Cm	-	centi metre
cP	-	centi Poise
cSt	-	centi Stokes
dmm	-	decimillimetre
DSR	-	Dynamic Shear Rheometer
DDT	-	Direct Tension Tester
g	-	gram
HMA	-	Hot-Mix Asphalt
Hz	-	Herzt
$G*$	-	Complex Shear Modulus
km	-	kilometre
kN	-	kilo Newton
kPa	-	kilo Pascal
lb	-	pound
m	-	metre
mg	-	milligram
min	-	minute
ml	-	millilitre
MPa	-	Mega Pascal
mN	-	milli-Newton
M_R	-	Resilient Modulus
ms	-	milli seconds
N	-	Newton

P	-	Pressure, Load
Pa.s	-	Pascal seconds
PI	-	Penetration Index
PVN	-	Penetration-viscosity number
R	-	Coefficient of correlation
R^2	-	R-square = coefficient of determination
rad	-	radian
rpm	-	revolution per minute
s	-	seconds
SG	-	Specific Gravity
SMA	-	Stone Mastic Asphalt
δ	-	phase angle
μm	-	microns
σ	-	Stress
τ	-	Shear stress
γ	-	Shear strain

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CHAPTER 1

INTRODUCTION

1.1 Background and Problem Statement

From the beginning of mankind, transportation, especially land transportation has been a main aspect in human lives. Communication and trade would not have been possible without it. For this purpose, thousands kilometers of road have been built over the world. Malaysia, the country with total land area of 329,847 square kilometers and population of 27,200,000 peoples (2007 estimate), has 91,620 km length of road consisting of 17,765 Federal roads and 73,855 km State roads [1].

Started from the pavements built on Crete during the Minoian period (2600 – 1150 B.C.) mankind continuously develop the construction of road. The famous ancient road construction was built by the Romans. It should be noted that these pavements were remarkably well designed. From those early days of the Roman Empire to the interstate highway system in the United States, roadway networks as well as roadway construction have been developed. The materials used for roadway construction have progressed with time.

In its development, pavements can be broadly classified into two types, flexible and rigid pavement. From the two types of roadway pavement, flexible pavement is the most used in the world at the moment. In Malaysia, for instance, from 91,620 kms length of road, 87,626 km or 95.64% are flexible pavement roads, and roads constructed with rigid pavement are only 343 kms or 0.37%, while the rest of 3,651 kms or 3.99% are earth/gravel roads [1]. In the United States as of 2001 there were about 2.5 million miles of paved roads of which 94% were bituminous surfaced [2]. Figure 1.1 shows basic flexible pavement structure

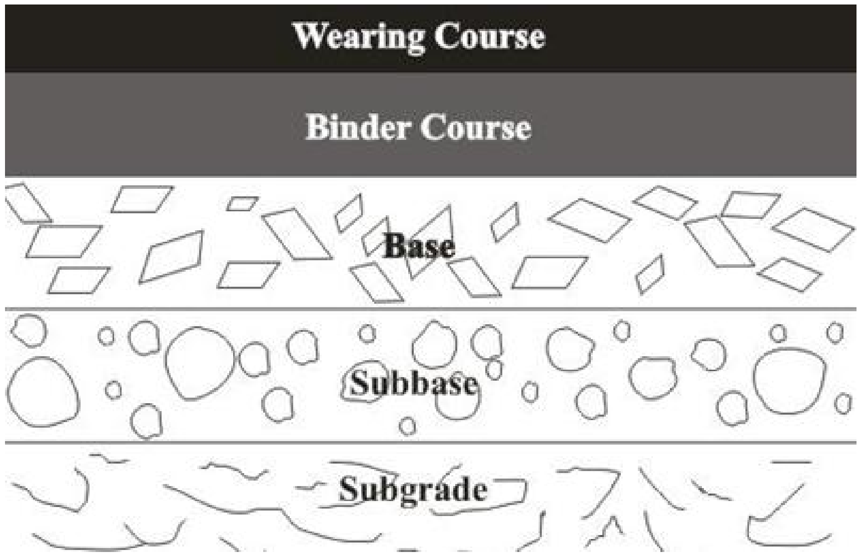

Figure 1.1: Basic flexible pavement structure

In most asphalt pavements, the stiffness in each layer or lift is greater than that in the layer below and less than that in the layer above. This could be understood from the load distribution (Figure 1.2) where the stress at the surface layer is higher than that of the layer below.

Surface layer has to withstand the maximum stress and bear the changing conditions of the environment. Therefore, this surface layer usually consists of the 'best' and most costly materials. Also, this layer is always 'bound', that is, mixed with a 'binder', in this case asphalt cement or bitumen binder, to prevent raveling materials under traffic, as well as to provide a dense surface to prevent ingress of water, unless it is an open graded friction course. Therefore, the surface layer has two major components, bitumen binder and aggregates.

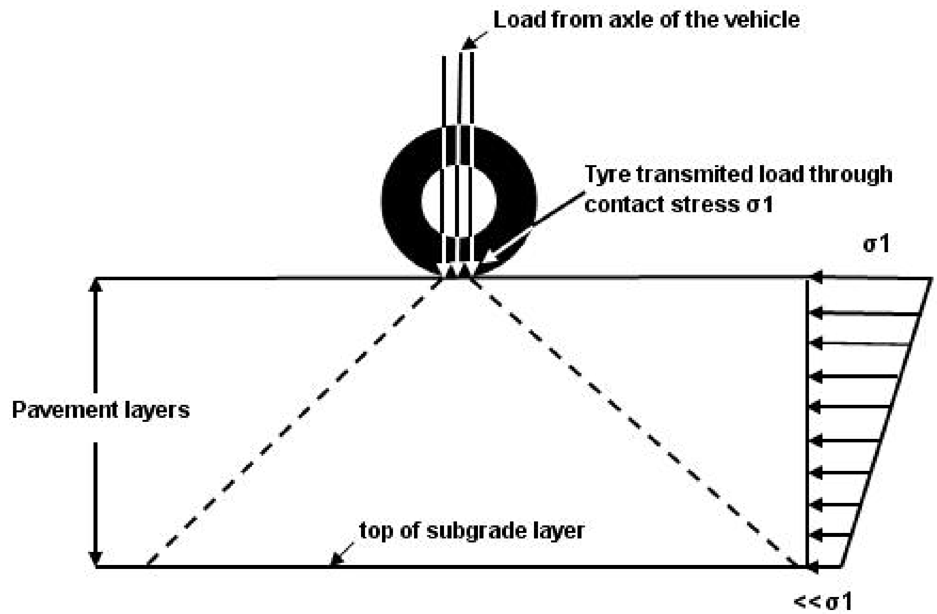

Figure 1.2: Load distributions on flexible pavement

The performance of asphalt pavements is mainly governed by the properties of the bitumen, because bitumen is the continuous matrix and only deformable component [2]. At high temperatures (40 to 60^{0}C), bitumen exhibits a viscoelastic behaviour. Pavement made of bitumen may show distress when exposed to high temperatures. At elevated temperatures, permanent deformation or rutting occurs and leads to channels in the direction of travel. This is attributed to the viscous flow of the bitumen matrix in paving mixtures, which retains strains induced by traffic. On the other hand, bitumen will brittle in low temperature and pavement cracking will occur. Therefore, pavement performance is strongly associated with the rheological properties of bitumen, which can be improved by its modification.

Bitumen is exposed to a wide range of load and weather conditions, however, it does not have good engineering properties, because it is soft in a hot environment and brittle in a cold weather. To prevent the occurrence of pavement distress, it is important to reinforced bitumen to improve its mechanical properties. Modified bitumen with additives to strengthen the mechanical properties of the bitumen has been practiced in many forms for over 150 years but there is a renewed interest. This resurgence in interest can primarily be attributed to the following factors [3, 4].

(1) The increase demand on HMA pavements. Traffic volume, and traffic loads, as well as tyre pressures have increased significantly in recent years causing premature rutting of HMA pavements.

(2) The new binder specifications recommended by Strategic Highway Research Program (SHRP) in March 1993 requires the bitumen binder to meet the stiffness requirements at high as well as low pavement service temperatures. Most base bitumen does not meet these requirements in the regions with extreme climatic conditions and, therefore, modification is needed.

(3) The environmental and economic pressure to dispose of some waste materials and industrial by products as additive in HMA.

(4) Public agencies willingness to pay a higher first cost for pavements with a longer service life or which will reduce the risk of premature distress (failure).

1.2 The Objective of the Research

From the above descriptions it is obvious that bitumen should be modified in order to improve its rheological properties or in order to withstand to use in the several of different temperatures. For that purpose, this research has the following objective:

a. To investigate the feasibility of using Oil Palm Fruit Ash (OPFA) as a bitumen modifier,

b. To formulate the mix between OPFA and bitumen that will result in a new binder with better physical and mechanical properties.

c. To evaluate the use of OPFA-modified bitumen (OPFA-MB) as a binder in stone mastic asphalt (SMA).

1.3 Scope of the Study

To accomplish those objectives, this study started with a literature review of the information pertaining to the relationship of bitumen characteristics on some different temperatures conditions, and characteristics of the present modified bitumen, and also tests which have to be conducted to the modified bitumen. Based on the results of the literature review, a research design was developed involving preliminary research to find the appropriate modifier, in this study was oil palm fruit ash (OPFA), as well as an extensive laboratory testing and experiments. In order to determine the minimum specification requirement of rheology characteristics of bitumen modification, various samples of OPFA-MB were prepared and tested by using of Dynamic Shear Rheometer (DSR), Bending Beam Rheometer (BBR), and Direct Tension Tester (DTT). OPFA-MB was then used as a binder of SMA. Various mix samples of SMA-14, the type of HMA used in this research, using OPFA-MB binder were prepared. Some tests on SMA-14 mixture to evaluate its performance were conducted by using Marshall Stability test, Indirect Tensile Resilient Modulus Test, and Indirect Tensile Creep or permanent deformation test, as well as rutting test by using of wheel tracking rutting test machine. Data obtained from the test were analyzed and conclusions and recommendations were made.

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