PERFORMANCE OF RECLAIMED ASPHALT PAVEMENT
REJUVENATED WITH MALTENE

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♥ *To My parents for their support and love* ♥

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ABSTRACT

Rejuvenating agents are considered desirable options for rejuvenating the reclaimed asphalt pavement (RAP) characteristics. However, some rejuvenating agents are not preferred due to their potential rutting damage when incorporated into the pavements, in addition to their poor practicality and durability for their medium to long-term usage. Based on these factors, this study aims to use the maltene as a rejuvenator. In phase I, maltene was extracted and characterised via several tests. In the next phase, a series of aged asphalt samples had been prepared with a range of maltene levels. Four physical tests were performed to determine the optimum dose of maltene. Next, the samples that contained an optimum percentage of maltene were analysed via rheological and chemical measurements. In the final phase, the performance of the rejuvenated asphalt mixtures was evaluated using several mechanical performance tests. Maltene was successfully extracted from a virgin asphalt (VA) using petroleum ether (with a ratio of 1 g asphalt: 5 mL petroleum ether). The gas chromatograph-mass spectrometer (GC–MS) spectra of maltene detected the right chemical compositions. Both physical and rheological traits of the blends containing 30%, 40% and 50% of aged asphalt were restored by incorporating 8%, 12% and 16% of maltene, respectively. The dynamic shear rheometer (DSR) and bending beam rheometer (BBR) analyses revealed an improvement in the performance of rejuvenated asphalts at both low and high temperatures. The Fourier transform infrared (FTIR) spectra of asphalt samples disclosed a decreasing in the chemical ageing index (CAI) and asphaltene content when the maltene was added to the asphalt. Meanwhile, the thermogravimetric analysis (TGA) indicated that the initial decomposition for rejuvenated asphalts was approximately close to VA. Other chemical and rheological traits of the rejuvenated asphalt disclosed its potency for practical applications. Accordingly, the mechanical characteristics results showed that maltene had been effective in mitigating the ageing effect of RAP. Marshall stability, indirect tensile strength (ITS), resilient modulus (M_R), and creep stiffness modulus (CSM) decreased when maltene was included into the RAP mixtures as a result of reducing the stiffness of aged asphalt. Meanwhile, the flow, creep strain slope (CSS) and rutting depth increased by adding maltene. In general, all the rejuvenated asphalt mixtures results exhibited better values than VA mixtures. Besides, the RAP mixture with maltene exhibited higher coating capability, good stripping and disintegration resistance. Therefore, RAP mixtures incorporating appropriate maltene dosage as rejuvenator could be effectively used in road construction.

ABSTRAK

Agen-agen peremajaan dianggap pilihan yang sesuai dalam meremajakan ciri-ciri turapan asfalt tebus guna (RAP). Walau bagaimanapun, beberapa agen peremajaan tidak menjadi pilihan disebabkan oleh potensi kerosakan aluran apabila digabungkan ke dalam turapan, sebagai tambahan kepada praktikal dan ketahanan yang lemah untuk penggunaan jangka sederhana hingga panjang. Berdasarkan faktor-factor ini, kajian ini bertujuan untuk menggunakan maltena sebagai egen peremajaan. Dalam fasa I, maltena telah diekstrak dan dicirikan melalui beberapa ujian. Pada fasa berikutnya, siri sampel asfalt tua telah disediakan dengan beberapa julat tahap maltena. Empat ujian fizikal telah dijalankan untuk menentukan dos maltena yang optimum. Seterusnya, sampel-sampel yang mengandungi peratusan maltena yang optimum telah dianalisis melalui pengukuran reologi dan kimia. Pada fasa terakhir, prestasi campuran asfalt yang diremajakan telah dinilai menggunakan beberapa ujian prestasi mekanikal. Maltena telah berjaya diekstrak daripada asfalt segar (VA) menggunakan petroleum eter (dengan nisbah 1 g asfalt: 5 mL petroleum eter). Spektrum kromatografi gas-spektrometri jisim (GC–MS) maltena telah mengesan komposisi kimia yang betul. Kedua-dua ciri fizikal dan reologi campuran yang mengandungi 30%, 40% dan 50% asfalt tua telah dipulihkan dengan memasukkan 8%, 12% dan 16% maltena, masing-masing. Analisis ricih dinamik reometer (DSR) dan lenturan rasuk reometer (BBR) menunjukkan peningkatan dalam prestasi asfalt diremajakan pada kedua-dua suhu rendah dan tinggi. Spektrum inframerah transformasi Fourier (FTIR) sampel-sampel asfalt mendedahkan penurunan dalam indeks penuaan kimia (CAI) dan kandungan asfaltena apabila maltena telah ditambah ke dalam asfalt. Sementara itu, analisis termogravimetri (TGA) menunjukkan bahawa penguraian awal untuk asfalt diremajakan adalah menghampiri kepada VA. Ciri-ciri kimia dan reologi lain asfalt yang diremajakan menunjukkan potensinya untuk penggunaan yang praktikal. Oleh itu, hasil ciri-ciri mekanikal menunjukkan bahawa maltena berkesan dalam mengurangkan kesan penuaan RAP. Kestabilan Marshall, kekuatan tegangan tidak langsung (ITS), modulus ketahanan (M_R), dan modulus kekukuhan (CSM) menurun apabila maltena telah dimasukkan ke dalam campuran RAP sebagai hasil pengurangan kekukuhan dalam penuaan asfalt. Sementara itu, aliran, kecerunan terikan rayap (CSS) dan kedalaman aluran meningkat dengan penambahan maltena. Secara amnya, semua hasil campuran asfalt yang diremajakan menunjukkan nilai yang lebih baik berbanding campuran VA. Selain itu, campuran RAP dengan maltena menunjukkan keupayaan salutan yang lebih tinggi, ketahanan perlucutan dan penyepaian yang baik. Oleh itu, campuran RAP yang digabungkan dengan dos maltena yang sesuai dapat digunakan sebagai agen peremajaan dengan berkesan dalam pembinaan jalanraya.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AASHTO		American Association of State Highway and Transportation Officials
ABCD	-	Asphalt Binder Cracking Device
AC14	-	Asphaltic Concrete of Nominal Aggregate Size 14 mm
ACV	-	Aggregate Crushing Value
AFM	-	Atomic Force Microscopy
AIV	-	Aggregate Impact Value
ANOVA	-	Analysis of Variance
APA	-	Asphalt Pavement Analyser
ASTM	-	American Society for Testing and Materials
BBR	-	Bending Beam Rheometer
BS EN	-	British Adoption of a European Standard
CAI	-	Chemical Ageing Index
CHNS	-	Carbon, Hydrogen, Nitrogen, and Sulphur
COI	-	Colloidal Index
CSM	-	Creep Stiffness Modulus
CSS	-	Creep Strain Slope
DSO	-	Date Seed Oil
DSR	-	Dynamic Shear Rheometer
DWT	-	Double Wheel Tracker
EDX	-	Energy Dispersive X-Ray
EI	-	Elongation Index
FESEM	-	Field Emission Scanning Electron Microscope
FI	-	Flakiness Index
FT	-	Fischer Tropsch
FTIR	-	Fourier Transform Infrared
GC–MS	-	Gas Chromatograph-Mass Spectrometer
G_{mm}	-	Maximum Specific Gravity
HMA	-	Hot Mix Asphalt
HWTT	-	Hamburg Wheel-Track Testing
IDT	-	Initial Decomposition Temperature

ITS	-	Indirect Tensile Strength
JKR	-	Jabatan Kerja Raya
KBC	-	Kemaman Bitumen Company
LAAV	-	Los Angeles Abrasion Value
LAS	-	Linear Amplitude Sweep
LMS	-	Large Molecular Size
LTA	-	Long Term Ageing
LVDT	-	Linear Variable Differential Transducer
MMS	-	Medium Molecular Size
MQ	-	Marshall Quotient
M_R	-	Resilient Modulus
OAC	-	Optimum Asphalt Content
PAV	-	Pressure Ageing Vessel
Pen.	-	Penetration
PG	-	Performance Grade
R and W	-	Riedel and Weber (R&W) Number
RAP	-	Reclaimed Asphalt Pavement
RRL	-	Road Research Laboratory
RTFO	-	Rolling Thin Film Oven
RV	-	Rotational Viscometer
SARA	-	Saturates, Aromatics, Resin, Asphaltene
SEM	-	Scanning Electron Microscope
SG	-	Specific Gravity
SMS	-	Small Molecular Size
STA	-	Short-Term Ageing
TGA	-	Thermogravimetric Analysis
TMD	-	Theoretical Maximum Density
TSR	-	Tensile Strength Ratio
TxDOT	-	Texas Department of Transportation
UA	-	Unaged
UMEO	-	Used Mobile Engine Oil
UV	-	Ultraviolet
VA	-	Virgin Asphalt

VFA	-	Voids Filled with Asphalt
V_S	-	Volume of Water Absorbed
VTM	-	Void in Total Mix
V_V	-	Volume of Voids
WCO	-	Waste Cooking Oil
WEO	-	Waste Engine Oil
WVO	-	Waste Vegetable Oil

LIST OF SYMBOLS

%	-	Percentage
cm	-	Centimetre
cm^{-1}	-	Reciprocal Wavelength
cm^2	-	Square Centimetre
cm^3	-	Cubic Centimetre
cP	-	Centipoise
dmm	-	Decimillimetre
ε	-	Strain
g	-	Gram
G^*	-	Complex Shear Modulus
hr	-	Hour
Hz	-	Hertz
kg	-	Kilogram
$KJ.\ Mol^{-1}$	-	Kilo Joule Per Mole
km	-	Kilometre
kPa	-	Kilo Pascal
L	-	Litre
mg	-	Milligram
mL	-	Millilitre
mm^2	-	Millimetre Square
mmHg	-	Millimetre of Mercury
MPa	-	Mega Pascal
N	-	Newton
nm	-	Nanometre
°C	-	Celsius
Pa.s	-	Pascal Second
rpm	-	Revolution Per Minute
sec	-	Second
δ	-	Phase Angle
θ	-	Angle

μ	-	Poisson Ratio
μm	-	Micrometre
σ	-	Stress

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Every year, valuable and non-renewable natural resources, especially asphalt and aggregate contained in asphalt mixtures, are extensively used for construction of road pavements. However, asphalt plants cause high-level pollution due to emission of greenhouse gases [1, 2]. Furthermore, abandoned asphalt pavements dumped into landfills cause serious environmental pollution and have turned into a major concern [3]. Hence, in order to surmount the emerging issues related to the extensive use of natural resources, numerous studies have begun seeking environmentally sustainable alternatives for pavement construction materials. Many have reported that milling the end-of-life pavements enables the use of reclaimed asphalt pavement (RAP) to produce asphalt mixtures, in which rejuvenating agents play a significant role [4-7]. The primary aim is to produce a rejuvenated asphalt mixture similar to that of virgin asphalt (VA) mixture. It has been acknowledged that the usage of RAP in hot mix asphalt (HMA) can be highly cost-effective [8, 9] with less exploitation of VA and aggregates [10], thus offering environmental and economic advantages [11].

Nevertheless, the physical properties and the characteristic composition of aged asphalt in RAP differ from those in VA [4, 12, 13]. As such, mixtures with high RAP percentage may possess undesired properties, such as high creep stiffness and viscosity, as well as low penetration and flexibility [14]. Besides, its cohesive properties are normally less than those of VA [15]. The brittleness property and other changes in asphalt are ascribed to the conversion of maltene fraction in asphalt into more viscous asphaltene fraction stemming from the ageing of asphalt throughout its service life [16-19].

The properties of aged asphalt as well as the performance of RAP mixtures can be rejuvenated to satisfy the requirements of the application by using a rejuvenating agent, soft asphalt, and sometimes, a rejuvenating agent with a polymer or fibre [12, 20, 21]. The use of soft VA with low RAP percentage is recommended, whereas rejuvenating agents should be applied when the RAP content is high (in excess of 25%) since several impracticalities may arise when soft asphalt is used in such instances [22, 23]. Rejuvenating agents can rebalance the ratio of maltene to asphaltene in aged asphalt by increasing the aromatic and resin contents in asphalt, thus minimising the relative content of asphaltene [24, 25], soften the aged asphalt, replenish volatiles, and enhance dispersion of asphaltene in maltene matrix [26, 27]. As a result, the viscosity and stiffness decrease, while the penetration depth increases, rendering the asphalt more ductile to attain a performance as close to the virgin as possible [28, 29]. Thus, enabling the inclusion of higher percentages of RAP in HMA without deteriorating the performance of asphalt [28]. Yu et al. [30] reported that using high quantities of resin and aromatic fractions may enhance the rejuvenating effect. Based on the aforementioned factors, this study had deployed maltene as a rejuvenator to restore the traits of aged asphalt and improve the performance of asphalt mixtures incorporating RAP.

1.2 Problem Statement

One main concern that hinders the integration of high RAP content in asphalt mixtures is that aged asphalt is more brittle, and may cause several drawbacks. This issue can be solved using rejuvenating agents. However, some rejuvenating agents are not preferred due to their potential rutting damage when incorporated into the pavements [31]. For instance, waste engine oil (WEO) and some petroleum-based products are beneficial solely for boosting asphalt performance at low temperatures, but making them unsuitable at high temperatures due to extreme softening of oil and ineffective aggregates-asphalt binding [32-34]. The other factors responsible for the rutting damage are low stiffness of the RAP surface micro-layer, as well as incompatible and ineffective blending between the rejuvenating agent and RAP binder (aged asphalt) [35]. The durability of rejuvenating agents is, however, another issue as the presence of volatile compounds in some softening agents can slightly reduce the asphalt stiffness to enable the eventual compaction and further improvement [20]. Apart from the durability characteristics of the rejuvenating agents, their chemical interaction with asphalt is also a vital factor as some rejuvenating agents can accelerate ageing, thus making asphalt unusable [20]. For instance, heavy fuel oils can easily volatilise at high recycling temperature, hence limiting the content of RAP in the asphalt mixture to be less than 30% [36].

Upon incorporation, the same rejuvenating agents can act differently in different asphalts. For example, an aromatic extract from crude oil revealed higher efficiency when used with asphalt (PG58-10) as opposed to asphalt (PG58-28), where it turned less efficient [30]. Poor practicality or durability of some rejuvenating agents for their medium- to long-term usage also poses several drawbacks [37]. For instance, plant oils (categorised as triglycerides) can decompose into smaller compounds in the presence of water, moisture, oxygen, ultraviolet (UV) radiation, or bacteria [38], thus limiting their applications as rejuvenating agents. Such shortcoming impedes the ability to use a high amount of RAP.

Referring to the aforementioned factors, maltene derived from VA was utilised in this study as a rejuvenator to address problems related to the attributes of RAP. The maltene (composed of high percentages of aromatic and resin, as well as low percentage of saturates) was selected due to its several characteristics, in comparison to other rejuvenating agents. Aromatic in maltene can increase the flexibility of asphalt, while resins can provide anti-rutting ability [39]. Other notable characteristics found in maltene are durability, good blending with virgin and aged asphalts, excellent dissolution in asphalt structure to ascertain uniformity, and exceptional compatibility, thus making it a practical rejuvenating candidate.

1.3 Aim and Objectives of the Study

This study examined the rejuvenation of RAP by incorporating maltene. The investigations undertaken in this study adhered to the following specific objectives:

1. To extract and characterise maltene to be used as a rejuvenator.
2. To investigate the physical, rheological and chemical properties of maltene-rejuvenated asphalt.
3. To evaluate the mechanical performance of hot mix asphalt incorporating different percentages of RAP and maltene as a rejuvenator.

1.4 Scope of the Study

This study sought to restore the properties of aged asphalt by embedding maltene derived from VA (penetration grade 60-70). The laboratory work comprised of asphalt binder and mixture evaluations. The methods were specified in accordance to those specified by Jabatan Kerja Raya (JKR), American Society for Testing and Materials (ASTM), American Association of State Highway and Transportation Officials (AASHTO), and British adoption of a European standard (BS EN). Essentially, several scopes and limitations demand clear definition, as follows: Pen. 60-70 asphalt was chosen as a VA. It was provided by Kemaman Bitumen Company (KBC) Malaysia. Maltene derived from VA was used as a rejuvenator. Granite aggregate was obtained from Hanson Quarry, Kulai, Johor. The RAP sample was retrieved from Yong Peng highway in the direction leading to Pagoh, Malaysia through milling process. The physical, rheological, and chemical properties of rejuvenated asphalt were determined using various percentages of maltene with different contents of aged asphalt. The asphalt mixtures of AC14 were used and designed in accordance with JKR to assess the mechanical properties of the asphalt mixtures. All tests were performed at UTM Skudai, Johor, except ductility test, that was conducted at

Universiti Tun Hussein Onn Malaysia Mara (UTHM), Batu Pahat, Johor, Malaysia and DSR test at Universiti Teknologi Mara (UiTM), Shah Alam, Malaysia.

1.5 Significance of Study

This study contributes to the economic, environmental, and engineering concerns. Asphalt mixtures made of asphalt and aggregate, which are extensively used for roadways (pavement layout) worldwide, are not only non-renewable but also costly, which must be overcome for the sake of sustainability [3]. Hence, recycling or reprocessing asphalt is a viable solution to enhance the sustainability and the cost-effectiveness of road pavement production [40, 41]. This helps to preserve non-renewable resources, eliminate wastage and disposal issues given it alleviates landfill dumping, as well as reduces energy consumption and service life expenditure by omitting virgin materials and fuel [5, 42].

Nevertheless, incorporating RAP in asphalt mixture may affect the attributes of a blend, which could result in major implications on the performance of asphalt mixture [4, 12]. Inclusion of maltene as a rejuvenator may enhance the characteristics of aged asphalt, thus making it similar or close to that of VA. The choice of maltene as the rejuvenator for aged asphalt had been based on the distinctive chemical and physical characteristics of this material. Maltene, being a key element in crude oil and asphalt materials, is easily obtained from asphaltene separation refinery units. Therefore, it is expected to provide significant economic advantages since the extraction and recovery of maltene are easy and economical processes. The proposed strategy of maltene for rejuvenating the properties of HMA containing RAP is useful to the strategic framework of international organisations and agencies for further sustainable deployment.

1.6 Thesis Outline

This thesis is composed of the following six chapters:

Chapter 1 provides a broad introduction and background to this study along with descriptions of the problem statement, objectives, scope, and significance of the study.

Chapter 2 comprehensively discusses studies performed by investigators in the field of RAP, rejuvenating agents and rejuvenated asphalt. The testing procedures, parameters, and related findings are described in this chapter.

Chapter 3 details the research plan and the procedure, which encompasses the following three stages of work: a method to produce and techniques to characterise maltene, tests and procedures to measure the physical, rheological, and chemical properties of asphalts, as well as evaluations that determine the performance of asphalt mixtures.

Chapter 4 presents the results of maltene extraction and characterisation, besides displaying the impact of maltene upon the physical, rheological and chemical characteristics of aged asphalts.

Chapter 5 describes a detailed investigation regarding the performance of RAP mixtures before and after rejuvenation.

Chapter 6 concludes the research and lists several recommendations for future endeavours.

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