EFFECTS OF WASTE ENGINE OIL ON WARM RECLAIMED ASPHALT MIXTURE

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Dedicated to my beloved husband, family and friends for the loves and encouragement.

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ABSTRACT

Depletion of natural resources and increase in energy consumption have led the pavement industry to actively explore innovative ways in creating sustainable infrastructure. In this context, the aim of this research was to investigate the modification of recycled binder and mixtures containing waste engine oil (WEO) with two types of warm asphalt additives; wax-based and oil-based. This study was divided into four phases. In the first phase, the WEO was blended with 0, 5, 10, 15 and 20 percent by weight of asphalt binder containing aged binder obtained from extraction and recovery of reclaimed asphalt pavement (RAP). The optimum WEO obtained from the first phase was blended with warm mix additives and tested in phase two. Two types of warm asphalt additives that had been applied were wax-based with dosages of 1%, 2%, and 3%, as well as oil-based with dosages of 0.3%, 0.4%, and 0.5% by weight of asphalt binder with WEO. These modified binders were subjected to storage stability, viscosity, rheology (temperature sweep, rutting resistance, and creep recovery), surface energy, as well as chemical characterization by using Fourier Transform Infrared Spectroscopy (FTIR) to determine the optimum additive content. In phase three, mechanical performance tests were performed by applying the optimum additive content obtained in phase two at compaction temperatures of 135°C, 125°C, and 115°C. The tests were resilient modulus, moisture resistance and rutting evaluation. In the final phase, the correlations between the properties of asphalt binder and the performance of the mixture had been determined by correlation coefficient analysis. The results show that 15% of WEO from various sources had been able to rejuvenate the aged binder to the base binder performance level. The optimum wax-based and oil-based additive contents were found to be 2% and 0.4%, respectively. The asphalt binder with wax-based additive improved the workability, hence displaying superior rutting resistance factor, better elastic response with reduced phase angle and reduction in aging level. Besides that, the mixture with wax-based additive exhibited higher resilient modulus, good moisture resistance, and acceptable lower rut depth, in comparison to other binders. The best compaction temperature was determined to be 135°C. In conclusion, the WEO emerged as a highly promising substance for modified binder with RAP and warm asphalt additive.

ABSTRAK

Pengurangan sumber asli dan peningkatan penggunaan tenaga telah mendorong industri turapan meneroka secara aktif kaedah inovatif untuk mewujudkan infrastruktur yang mampan. Dalam konteks ini, matlamat kajian adalah untuk menyiasat pengubahsuaian pengikat asfalt kitar semula dan campuran yang mengandungi minyak enjin terbuang (WEO) dengan dua jenis bahan tambah asfalt suam; berasaskan lilin dan berasaskan minyak. Kajian ini dibahagikan kepada empat fasa. Dalam fasa pertama, WEO diadun dengan 0, 5, 10, 15 and 20 peratus daripada berat bahan pengikat asfalt yang mengandungi pengikat lama yang diperolehi daripada pengekstrakan dan pemulihan daripada turapan tebus guna (RAP). WEO optimum yang diperolehi daripada fasa pertama dicampur dengan bahan tambah suam dan diuji dalam fasa kedua. Dua jenis bahan tambah campuran suam yang digunakan adalah berasakan lilin dengan dos yang berbeza iaitu 1%, 2% dan 3%, serta berasaskan minyak pada kadar 0.3%, 0.4% dan 0.5% daripada berat bahan pengikat asfalt dengan WEO. Bahan pengikat yang diubahsuai ini diuji untuk kestabilan penyimpanan, kelikatan, reologi (perbezaan suhu, rintangan aluran dan pemulihan rayapan), tenaga permukaan serta pencirian kimia dengan menggunakan *Fourier Transform Infrared Spectroscopy* (FTIR) untuk menentukan kandungan optimum bahan tambah. Dalam fasa ketiga, ujian-ujian prestasi mekanikal dijalankan dengan menggunakan kandungan optimum bahan tambah yang diperoleh dari fasa kedua pada suhu pemadatan 135°C, 125°C dan 115°C. Ujian-ujian yang dijalankan adalah ujian modulus keanjalan, rintangan kelembapan dan penilaian aluran. Dalam fasa akhir, korelasi antara sifat pengikat asfalt dan prestasi campuran ditentukan dengan analisis pekali penentuan. Keputusan menunjukkan bahawa 15% WEO dari pelbagai sumber yang berbeza dapat meremajakan pengikat lama kepada aras prestasi asfalt asas. Kandungan optimum bahan tambah berasaskan lilin dan minyak masing-masing adalah 2% dan 0.4%. Pengikat asfalt dengan bahan tambah berasaskan lilin didapati meningkatkan kebolehkerjaan, seterusnya mempamerkan faktor rintangan aluran yang lebih bagus, tindak balas elastik yang lebih baik dengan mengurangkan sudut fasa dan mengurangkan tahap penuaan. Di samping itu, campuran dengan bahan tambah berasaskan lilin menunjukkan nilai modulus keanjalan yang lebih baik, rintangan kelembapan yang bagus dan kedalam aluran yang boleh diterima pakai berbanding campuran lain. Suhu pemadatan yang terbaik ditentukan pada 135°C. Sebagai kesimpulan, WEO muncul sebagai bahan yang meyakinkan untuk bahan pengikat ubah suai bersama RAP dan bahan tambah suam.

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LIST OF ABBREVIATIONS

AASHTO	-	American Association of State and Highway Transportation Officials
APA	-	Asphalt Pavement Analyzer
ARRA	-	Asphalt Recycling and Reclaiming Association
ASTM	-	American Society for Testing and Materials
ATR	-	Attenuated Total Reflectance
DSR	-	Dynamic Shear Rheometer
EAPA	-	European Asphalt Pavement Association
FTIR	-	Fourier Transform Infrared Spectroscopy
HMA	-	Hot Mix Asphalt
ITRM	-	Indirect Tensile Resilient Modulus
ITS	-	Indirect Tensile Strength
LVDT	-	Linear Variable Displacement Transducer
NAPA	-	National Asphalt Pavement Association
NMAS	-	Nominal Maximum Aggregate SRTize
RAP	-	Reclaimed Asphalt Pavement
RTFO	-	Rolling Thin Film Oven
TSR	-	Tensile Strength Ratio
UTM	-	Universal testing machine
UV	-	Ultraviolet
VFA	-	Voids filled with asphalt
VMA	-	Voids in mineral aggregates
WEO	-	Waste Engine Oil
WMA	-	Warm Mix Asphalt

LIST OF SYMBOLS

δ	-	Phase angle
°*C*	-	Degree Celsius
cm	-	Centimeter
g	-	Gram
*G**	-	Complex shear modulus
$G^*/\sin\delta$	-	Rutting resistance
G_{mb}	-	Bulk specific gravity of compacted mixture
G_{mm}	-	Maximum specific gravity of loose mixture
G_{sb}	-	Bulk specific gravity of total aggregate
J_{nr}	-	Non-recoverable compliance
kPa	-	Kilopascal
mJ/m^2	-	Millijoule per square meter
mL	-	Milliliter
mm	-	Millimeter
MPa	-	Megapascal
N_{des}	-	Design number of gyrations
N_{ini}	-	Initial number of gyrations
N_{max}	-	Maximum number of gyrations
Pa.s	-	Pascal second
P_{be}	-	Effective Asphalt Content
r	-	Correlation Coefficient
rpm	-	Revolution per minute
s	-	Second
V_a	-	Volume of air voids

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Nowadays, environmental issues have become a significant challenge to society due to increase population, over-exploitation and depletion of natural resources. These issues have also been highlighted in the field of road construction and rehabilitation. Flexible road infrastructure is a sector that uses a sizeable amount of aggregate and asphalt binder which are categorized as non-renewable materials. The fast depletion of these natural non-renewable materials and their escalating price have urged the asphalt industries to look for other alternatives to achieve sustainable pavement, whicht is defined by Miller and Bahia (2009) as:

"…..*a pavement that minimizes environmental impacts through the reduction of energy consumption, natural resources and associated emissions while meeting all performance conditions and standards.*"

Therefore, the recycling of end-service life asphalt pavement has become a viable solution to the aforementioned scenario. Generally, the material is known as reclaimed asphalt pavement (RAP). It can be produced through the milling process, demolition process (breaking and lifting up pavement in slabs), waste of asphalt production plant and unwanted loads return from the laying site (Hunter *et al*., 2015). Recycling pavement materials have some advantages to the environmental, economic and engineering aspects. They help to offset the increased initial cost, conserve natural resources and avoid disposal problems (Jamshidi *et al*., 2012).

Over the years, RAP was used in the conventional method of hot mix asphalt (HMA) since the production and road construction using RAP require high temperature (Sondag *et al.*, 2002; Widyatmoko, 2008; McDaniel *et al.*, 2012; Izaks *et al.*, 2015). HMA is usually produced at the temperature between 160ºC and 170°C. This range of temperature of HMA encourages the asphalt binder within the RAP to undergo a secondary ageing that causes compatibility and workability issue during compaction (Tao and Mallick, 2009; Guo *et al.*, 2016). The soft binder grades were expected to reduce the stiffness in mixtures with high RAP (Sabouri *et al.*, 2015; Ekblad and Lundström 2017). Waste engine oil (WEO) is one of the rejuvenators that is able soften the aged binder in RAP.

Additionally, warm mix asphalt (WMA) is the recent advanced technology which allows the reduction of temperature, reduces energy consumption, increases RAP content usage and has certain environmental benefit, spurring the interest of engineers and practitioners in the pavement industry (Rubio *et al*., 2012). However, the effects of WMA on reclaimed asphalt binder are depending on the types of additives (Rogers, 2011; Buss *et al*., 2015; Sabouri *et al*., 2016). The term ‘sustainability’ has sparked the interest of industries and researchers to continuously support and promote the utilization of waste materials in construction materials without compromising the performance. This study explored the usage of WEO as rejuvenator for RAP with WMA technology. Both WEO and RAP may encourage innovative application of waste materials in pavement when they are used simultaneously with WMA at a low temperature. In particular, there is a scarcity of information in understanding the effect of those materials on the binder and mixture properties. Therefore, this study was extensively conducted to explore the potential of waste material in sustainable development.

1.2 Problem Statement

Most studies on the modification of mixture containing RAP point out that the stiffness of the RAP binder is one of the intrinsic properties which restricts a higher percentage of RAP. The stiffness causes loss of flexibility, workability problem (Zaumanis *et al*., 2013a), susceptible to crack failure (Zaumanis *et al.*, 2015), reduced fatigue life (Tao and Mallick, 2009), lowered strain tolerance (Tran *et al.*, 2012) and physical change (Chen *et al.*, 2007). These problems can be mitigated effectively by the WEO. Their appearance similarity, high availability due to increasing number of vehicles and the recoverable of the flexibility of RAP binder which is similar to rejuvenating agent, have led to the usage of WEO in pavement.

WEO is a material that is capable to soften the oxidative aged binder (Zamhari *et al*., 2009 ; Oliveira *et al.*, 2013; DeDene and You, 2014). In Malaysia, there is an estimation of 27 million registered vehicles with around 12 million of motorcars (JPJ, 2016). Consequently, it has contributed to high amount of waste oil disposal. Figure 1.1 shows the numbers of registered motorcars per year. After a certain period of usage, the vehicles need to be serviced. In a single automotive oil change, 4 to 5 liters of WEO will be disposed. Without proper handling, it can lead to environmental problems. WEO can be used as a recycled material in pavement through asphalt binder modification. Alternatively, it could be recycled as pavement materials through asphalt binder modification. However, the application of WEO could reduce the cohesive strength of virgin asphalt binder (Borhan *et al*., 2009) and the strength of asphalt mixture in the hot mix asphalt (DeDene and You, 2014).

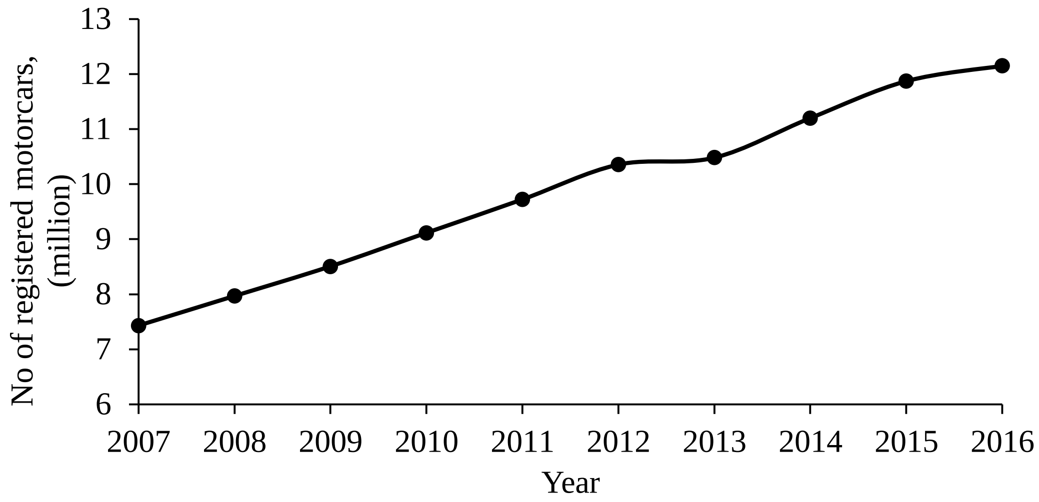

Figure 1.1 Number of registered motorcars from 2007 to 2016 (JPJ, 2016)

On the other hand, the RAP binder is reported to have larger influence compared to WMA additive and thus, limits the incorporation of higher recycled asphalt materials (Buss *et al.*, 2015). The identified problem is due to the temperature and binder factor. These issues have led to the motivation in conducting this study; the mergence of WEO, RAP and WMA. Therefore, a thorough investigation of the modified binder properties and mixture performance was conducted in a well-controlled laboratory.

1.3 Aim and Objectives of Study

The aim of this study was to investigate the feasibility of reclaimed asphalt pavement (RAP) containing waste engine oil (WEO) with warm mix asphalt (WMA) technology. Four objectives were formulated as follows.

1) To determine the amount of waste engine oil (WEO) required to rejuvenate the aged binder

2) To investigate the effect of different percentages of wax-based and oil-based additives on the properties of the aged binder containing WEO

3) To investigate the mechanical performance of pavement mixture with modified binder in terms of stiffness, moisture resistance and rutting at different mixing and compaction temperatures.

4) To develop a correlation between the properties of modified binder with warm mix asphalt (WMA) mixture performances

1.4 Scope of Study

The main focus of this research is the characterization of the recycled asphalt binder modification with WEO in WMA for wearing course. The methods were specified according to the American Society for Testing and Materials (ASTM) and American Association of State Highway and Transportation Officials (AASHTO).

The laboratory works consisted of binder and mixture evaluations. Base binder of penetration grade 80/100 was used as the control binder. WEO was obtained from local service center. Two types of WMA additives were used in this study: wax-based and oil-based. The RAP sample was obtained from a resurfacing project by milling process at Jalan Batu Pahat. In the first phase, five sources of WEO were tested. Only one source was used for the second phase due to no significant difference between the sources of WEO. The selected WEO was blended with various percentages of wax-based and oil-based additives, respectively. The best amount of each type of additive was further used in phase three.

Since the trigger was the intrinsic property of asphalt binder, the laboratory tests were conducted to determine the modified asphalt binder properties and mixture performance. The purpose of performing the tests was to understand the interaction between the materials in the pavement in an early aged-stage. Early aged stage refers to the condition after manufacturing and construction of pavement which is influenced from the asphalt binder properties.

1.5 Significance of Study

WEO with high compatibility with asphalt binder was used in the pavement modification. However, the modification could not be done indiscriminately. There is a need for a detailed study to propose this waste material to be used in pavement sustainably without adversely affecting the pavement performance. Therefore, this research was mainly conducted to develop a better understanding of the WEO modification in high RAP binder with WMA from a fundamental point of view.

The application of WMA technology during the rejuvenation process of recycled mixture containing WEO was considered as a "green-on-green" concept. This technology could be an alternative to reduce waste disposal to the environment, and decrease the production temperature and energy consumption by improving the mechanical performance of the final mixture. The objective of using recycled technology was to ensure that the material can perform better or at least comparable to other conventional materials. The findings of this study could be of interest to the asphalt industry as well as to support the target of Malaysian Public Work Department Strategic Framework that focuses on sustainable infrastructure and asset development.

1.6 Thesis Outline

This thesis is divided into five chapters. A brief description of each chapter is provided as follows:

Chapter 1: Introduction **-** This chapter includes a brief background of this study. The research chronology is divided into problem statement, research objectives, scope and significance of the study.

Chapter 2: Literature Review - This chapter presents the fundamental about reclaimed asphalt pavement (RAP). The intrinsic properties in RAP binder lead to the modification. The evaluation of the modification is reviewed. Concluding remarks are presented at the end of this chapter regarding the modification of RAP, WEO and WMA.

Chapter 3: Research Methodology **-** This chapter describes the experimental framework, details of the apparatus, sample preparation and testing procedure. Four phases are involved in the methodology. Each phase represents each objectives.

Chapter 4: Results and Discussions - This chapter discusses the findings according to the four phases as outlined in Chapter 3. Each chapter is interrelated in order to achieve the objectives.

Chapter 5: *Conclusions and Recommendations* **-** This chapter presents summary of the findings and recommendations for future studies.

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