REPEATABILITY OF RECLAIMED ASPHALT PAVEMENT

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REPEATABILITY OF RECLAIMED ASPHALT PAVEMENT

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To my beloved family

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ABSTRACT

Usage of fresh bitumen and aggregates in pavement construction and rehabilitation can be minimised by utilising reclaimed asphalt pavement (RAP). RAP is a waste material generated from old or damaged pavement surface. Although it has been practiced since 1970s and several suggestions on the usage of RAP in the new mixture have been introduced, there is a limited number of research has been found, discussing on the issue of second recycling of RAP (R^2AP). Pavement made with RAP will reach the end of service life and there is a need to recycle again. This study focused on investigating the performance of mixtures incorporating RAP and R^2AP. It was carried out in three phases. In the first phase, three ageing procedures consisted of eight laboratory ageing methods were conducted to select suitable method that produced most severe ageing effect. Ageing methods used were combination of rolling thin film oven (RTFO), pressure aging vessel (PAV), short term oven ageing (STOA) and long term oven ageing (LTOA). In the second phase, mixture tests were conducted to evaluate the performance of asphaltic concrete with 14 mm nominal maximum aggregate size (AC 14) mixture incorporating RAP and R^2AP. Final phase involved the physical, rheological and chemical property tests of aged bitumen. Penetration, softening point, viscosity, dynamic shear, elemental analysis and Fourier transform infrared (FTIR) tests were performed on the bitumen which were extracted from the selected mixtures. Three mixtures consisted of 20, 40 and 60% RAP were evaluated in the first cycle and four mixtures consisted of 20, 40, 60 and 80% R^2AP were evaluated in the second cycle. Results show that seven days of LTOA is the most suitable ageing method for AC 14. Mixture consisted of 40% RAP shows a better performance when it was mixed with 80-100 PEN (B1) bitumen whereas mixture with 60% RAP performed better with 60-70 PEN (B2) bitumen compared to other mixtures. After seven days of LTOA, mixture consisted of 40% R^2AP mixed with B1 and 40% R^2AP mixed with B2 show better performance compared to other recycled mixtures. Physical, rheological and chemical analyses of the extracted bitumen also indicated that there were acceptable differences between first and second cycle. Hence, it is proven that R^2AP is suitable to be used as an alternative material to minimise the usage of fresh bitumen and aggregates. Based on regression model of aged bitumen properties, it can be concluded that RAP was suitable to be recycled up to second time.

ABSTRAK

Penggunaan bitumen dan agregat segar dalam pembinaan dan pemulihan turapan dapat diminimumkan dengan penggunaan turapan tebus guna (RAP). RAP adalah bahan buangan yang terhasil daripada permukaan turapan lama atau rosak. Walaupun ia telah dipraktikkan sejak 1970an dan pelbagai cadangan berkenaan penggunaan RAP di dalam campuran baru telah diperkenalkan, kajian membincangkan tentang isu kitar semula RAP kali kedua (R^2AP) yang ditemui adalah terhad. Turapan yang diperbuat daripada RAP akan mencapai penghujung jangka hayat perkhidmatannya dan perlu dikitar semula sekali lagi. Kajian ini memberi tumpuan untuk menyiasat prestasi campuran yang mengandungi RAP dan R^2AP. Ianya dijalankan dalam tiga fasa. Dalam fasa pertama, tiga prosedur penuaan yang terdiri daripada lapan kaedah penuaan di makmal telah dilaksanakan untuk memilih prosedur yang memberi kesan penuaan yang paling ketara. Kaedah penuaan yang digunakan adalah gabungan antara *rolling thin film oven* (RTFO), *pressure ageing vessel* (PAV), penuaan ketuhar jangka pendek (STOA) dan penuaan ketuhar jangka panjang (LTOA). Dalam fasa kedua, ujian campuran dilaksanakan untuk menilai prestasi campuran konkrit berasfalt dengan 14 mm saiz nominal maksimum agregat (AC 14) yang mengandungi RAP dan R^2AP. Fasa terakhir melibatkan ujian ciri-ciri fizikal, reologikal dan kimia *aged bitumen*. Ujian penusukan, titik lembut, kelikatan, *dynamic shear*, analisis elemen dan *Fourier transform infrared* (FTIR) telah dilaksanakan ke atas bitumen yang diesktrak daripada campuran terpilih. Tiga campuran terdiri daripada 20, 40 dan 60% RAP dinilai dalam kitaran pertama dan empat campuran terdiri daripada 20, 40, 60, 80% R^2AP telah dinilai dalam kitaran kedua. Keputusan menunjukkan tujuh hari LTOA adalah kaedah penuaan yang paling sesuai untuk AC 14. Campuran mengandungi 40% RAP menunjukkan prestasi yang lebih baik jika dicampur dengan bitumen 80-100 PEN (B1) sementara campuran dengan 60% RAP menunjukkan prestasi yang lebih baik jika dicampur dengan bitumen 60-70 PEN (B2) berbanding campuran lain. Selepas tujuh hari LTOA, campuran yang mengandungi 40% R^2AP dicampur dengan B1 dan 40% R^2AP dicampur dengan B2 telah menunjukkan prestasi yang lebih baik berbanding campuran lain. Analisis fizikal, reologikal dan kimia daripada bitumen yang diekstrak juga menunjukkan terdapat perbezaan yang boleh diterima antara kitaran pertama dan kedua. Oleh itu, ini membuktikan bahawa R^2AP sesuai untuk digunakan sebagai bahan alternatif bagi meminimumkan penggunaan bitumen dan agregat segar. Daripada model regrasi ciri-ciri *aged bitumen*, dapat disimpulkan bahawa RAP sesuai dikitar semula untuk kali kedua.

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LIST OF ABBREVIATIONS

AASTHO	-	American Association of State Highway and TransportationOfficials
AC 10	-	Asphaltic concrete of nominal maximum aggregate size 10 mm
AC 14	-	Asphaltic concrete of nominal maximum aggregate size 14 mm
AC 28	-	Asphaltic concrete of nominal maximum aggregate size 28 mm
ANOVA	-	Analysis of Variance
ARRA	-	Asphalt Recycling and Reclaiming Association
ASTM	-	American Society for Testing and Materials
BS	-	British Standard
CSS	-	Creep strain slope
C=O	-	Carbonyl band
DSR	-	Dynamic shear rheometer
ERTFOT	-	Extended rolling thin film oven test
FHWA	-	Federal Highway Administration
FTIR	-	Fourier Transform Infrared
ITS	-	Indirect tensile strength
JKR	-	Jabatan Kerja Raya
LTOA	-	Long term oven ageing
LVDT	-	Linear Variable Displacement Transducer
MS	-	Malaysia Standard
NCHRP	-	National Cooperative Highway Research Program
NRTFOT	-	Nitrogen rolling thin film oven test
OBC	-	Optimum bitumen content
OPC	-	Ordinary Portland cement

PAV	-	Pressurized ageing vessel
RAP	-	Reclaimed asphalt pavement
R^2AP	-	Second reclaimed asphalt pavement
RCA	-	Recycled concrete aggregate
RCAT	-	Rotating cylinder ageing test
RTFO	-	Rolling thin film oven test
SHRP	-	Strategic Highway Research Program
STOA	-	Short term oven ageing
S=O	-	Sulfoxide band
TMD	-	Theoretical maximum density
TFOT	-	Thin film oven test
VFB	-	Voids filled with bitumen
VMA	-	Voids in mineral aggregates
VTM	-	Voids in total mix

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

In pavement design, flexible pavement is typically designed for about ten to fifteen years. During the service life, rehabilitation and maintenance activities are very crucial in order to ensure quality and improve serviceability of the particular road. Thus, demand on pavement materials is not only limited during the initial construction but it will continue throughout the service life. Nowadays, construction industry gives a greater attention on sustainability aspect. Sustainability issue in road construction focuses more in providing ways on how to reduce virgin materials, energy and waste in construction, without compromising the quality of the pavement itself. There are many factors contributing to the sustainable construction such as construction methods, design processes, machineries and materials used for the construction.

Furthermore, price of virgin or fresh construction materials keep on rising as a result of rapid development and depletion of natural recourses. Demand for bitumen and aggregate for road construction is reflected as well. Figure 1.1 shows the market price trend of bitumen for peninsular and east Malaysia. The price index is based on the price of bitumen 80-100 PEN. The same trend occurred in the market price of aggregate as in Figure 1.2. It shows the price of 10 mm, 20 mm and 40 mm aggregates which are commonly used for wearing and binder course of pavement in Malaysia. Due to the price increased, Malaysia government spends about RM 20 billion for road construction and maintenance in 2015 (Abdelfatah *et al*., 2015).

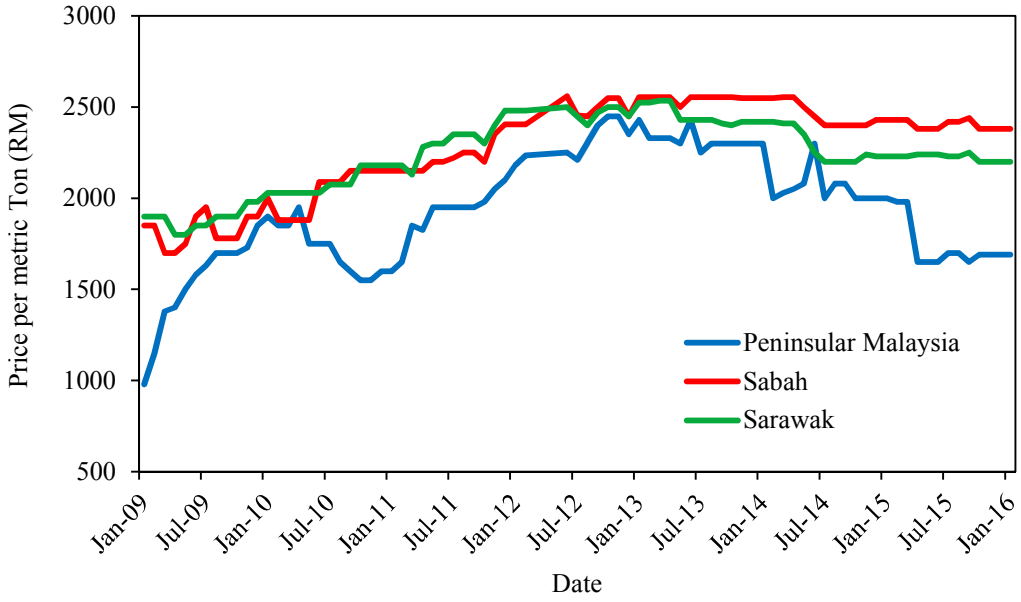

Figure 1.1: Average unit price of bitumen in Malaysia. (Jabatan Perangkaan Malaysia, 2016a; Jabatan Perangkaan Malaysia, 2016b)

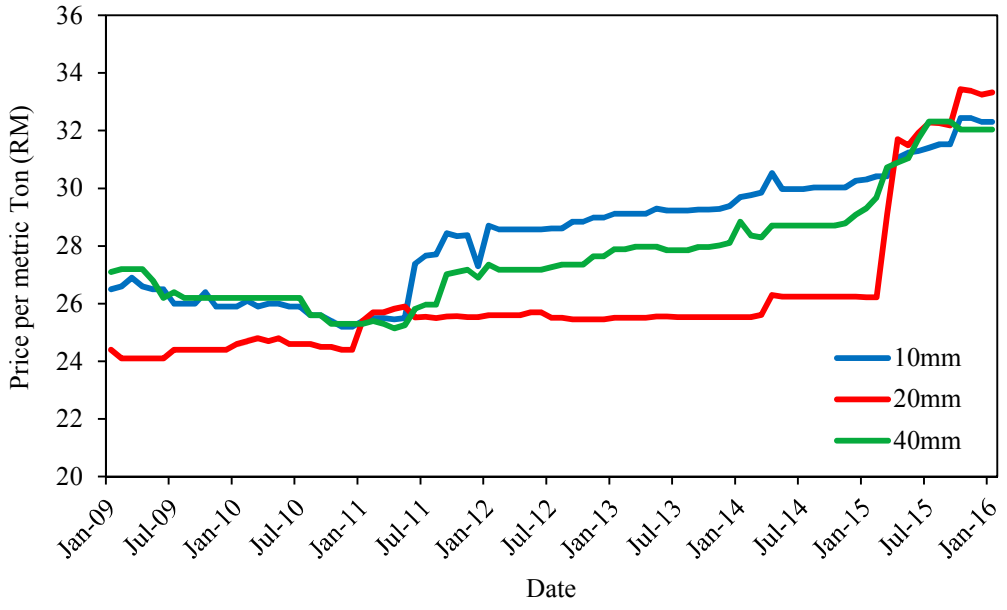

Figure 1.2: Average unit price of aggregates in Malaysia. (Jabatan Perangkaan Malaysia, 2016a; Jabatan Perangkaan Malaysia, 2016b)

Materials recycling is one of the best solution that support sustainability aspect at the same time reduce the construction and material cost. Recycling a bituminous pavement is not a new idea. Advancements in recycling technology and equipment

occurred in 1970s. It conserved energy and non-renewable natural resources, preserved environment, reduced the usage landfill, reduced cost for construction and improved the overall pavement performance (Asphalt Recycling and Reclaiming Association, 2001).

One of the common methods in bituminous recycling is by using reclaimed asphalt pavement (RAP). RAP consists of waste materials, obtained from the milling process of pavement surface (wearing course, binder course or both). RAP will be mixed with fresh aggregates, bitumen, with or without recycling agents to produce a recycled mixture. Although usage of RAP in the pavement has been established, the performance and properties of recycle RAP (R^2AP) is unclear. Very few documented research on R^2AP has been reported and the knowledge on this need to be further explored. Therefore, a study in this area is really needed in order to address the suitability and effectiveness of RAP and R^2AP for a better implementation of sustainability in road construction. Furthermore, properties of aged bitumen extracted from the respective mixtures were evaluated to forecast the recyclability of the mixture.

1.2 Statement of the Problem

During the pavement service life, rehabilitation is required to optimize the performance by improving the serviceability of the road. It may involve reconstruction, recycling or overlay of the surface materials. However, the continuous demand on the construction materials lead to the depletion of natural resources and increase the waste materials. Recycling of bituminous pavement materials is found to be the best method to minimize the usage of natural resources and to solve the materials disposal issues.

Many studies have proved that RAP could be incorporated into the pavement mixture for the first time. Furthermore, it has been practiced since 1970s and several suggestions on usage of RAP have been established. For example, few places in the US have successfully used RAP in the pavement mixture on site (Federal Highway

Administration, 2016). However, there are still mixed findings on the performance of RAP were discovered among the researchers especially on the suitable amount of RAP to be incorporated in the mixture. For example Yang and Lee (2016) suggested that RAP should be less than 25% from the total mixture, but other researcher claimed that higher RAP content with proper handling is still capable to perform as good as conventional mixture (Poulikakos *et al.,* 2014).

In addition, those pavements made with RAP will reach the end of service life. The same problem will occur during the second phase of rehabilitation on how to deal with milled RAP (R^2AP) for the second time. Most of the existing research on RAP typically concentrate on evaluating the performance of mixture incorporating RAP while performance and properties of R^2AP is very limited and still debatable. In R^2AP study, Chen *et al.* (2009) suggested that up to 40% R^2AP did not alter the mixture properties and performance, while Su *et al.* (2008) claimed that there are no distinct in certain parameter between conventional and second recycled mixture consists R^2AP.

Issues on different materials and climate also have led to a motivation in conducting this study, where it will be more specifically suits for tropical region Furthermore, findings of this research are also essential to improve public perception on the usage of waste materials especially R^2AP in road construction. It is also expected that the findings can be used as a fundamental guideline to recommend the suitable proportion of RAP in road construction. Overall, this research is very significant to encourage relevant parties to conduct more studies and practices on the usage of RAP in the road construction.

1.3 Objective of the Study

The aim of this study was to determine the recyclability of bituminous mixture. The aim was achieved through the following objectives:

a) To determine and select an appropriate method of laboratory ageing, which could produce most severe ageing effect on the mixture;

b) To evaluate the performance of bituminous mixtures incorporating RAP and R^2AP (recycled mixtures) in term of rutting and cracking resistances;

c) To determine the physical, rheological and chemical properties of aged bitumen extracted from recycled mixtures;

d) To forecast recyclability of the mixture based on the properties of aged bitumen.

1.4 Scope of the Study

The scopes of the study were:

a) Recycled bituminous mixtures were designed by incorporating RAP and R^2AP which are compatible with the conventional bituminous mixture.

b) Mixture gradations used in this study were design in accordance to JKR (JKR, 2008).

c) Four laboratory ageing methods were used in the first phase. Combinations of two ageing methods were then classified as a complete ageing process.

d) Three ageing processes were examined in first phase and the best process that produced the most severe ageing effect was used in second phase.

e) Two grades of fresh bitumen (80-100 PEN and 60-70 PEN) were utilized in this study.

f) Performance of the mixtures was evaluated based on laboratory samples and tests.

1.5 Thesis Structure

This thesis is organised into five chapters. Each chapter consists of several sections and sub-sections. The chapter details are explained as follows:

Chapter 1: Introduction

Chapter 1 briefly describes the overall perspectives of the research including background, problem statement, aim and objectives that need to be achieved.

Chapter 2: Literature Review

Chapter 2 provides a comprehensive review from previous research and experiences related to laboratory ageing process, usage of RAP in bituminous mixture and properties of extracted binder from aged mixtures.

Chapter 3: Research Methodology

Chapter 3 explains in details the process and methods used in this research. It includes materials, equipment, procedures and standards applied throughout the research. The research was designed and conducted in three different phases.

Chapter 4: Result and Discussion

Chapter 4 presents the findings from the experimental results. The results were organised in three sections in line with the phases described in Chapter 3.

Chapter 5: Conclusion and Recommendation

Chapter 5 summarises the findings with conclusions and several recommendations for future research.

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