RHEOLOGICAL PROPERTIES OF STYRENE-BUTADIENE-RUBBER MODIFIED BITUMEN

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A project report submitted in partial fulfillment of the
requirements for the award of the degree of
Master of Engineering (Civil- Transportation and Highway)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

JANUARY 2015

This project report is dedicated to my parents
for their endless support and encouragement

ACKNOWLEDGEMENT

I would like to express my gratitude to all those who gave me a helping hand to complete this thesis. I am particularly grateful to my supervisor **Dr. Ramadhansyah Putra Jaya** for his valuable and constructive suggestions that helped me in completing this project. Thank you for your efforts in improving our study.

I would also like to express my gratitude to **Prof**. **Dr. Mohd. Rosli Hainin *(Head of Department)*** and **Dr. Norhidayah Abd Hassan,** for allowing us to work in the laboratory.

Thanks to the **technicians and individuals** who offered their help directly or indirectly in Highway laboratory. Gratitude also dedicated to all my **friends** who helped and supported me during all the way upon completing thesis.

Furthermore I wish to thank my **Parents** who have supported me throughout this entire process. Without their prayers and support I would have never completed this project.

Finally, a special thanks to my teacher **Dr. Naeem Aziz Memon** for his valuable advices which helped me throughout my entire Master's program.

ABSTRACT

This study investigates the rheological properties of bitumen (asphalt) binder penetration grade 60-70 modified with an additive Styrene Butadiene Rubber (SBR). SBR is an elastomer which is the important sort of synthetic rubber. It is a copolymer which consists of organic compound styrene and butadiene chain which makes up its molecular structure. Bitumen is visco-elastic material where temperature and rate of load application have a great influence on their performance. The properties evaluated include the rheological properties of the modified bitumen binder. These properties were complex shear modulus G* using Dynamic Shear Rheometer (DSR), short term aging by Rolling Thin Film Oven Test (RTFOT), long term aging by Pressure Aging Vessel (PAV), viscosity by Rotational Viscometer (RV), penetration by Penetro meter and softening point by Ring and Ball test. Results obtained from the study indicated the effect of SBR on the binder, and also depends on the quantity (%) of the additive used and test temperature. The binders were mixed with various percentages of the SBR at the 1, 2, 3, 4 and 5% by weight of bitumen binder. Using the SBR showed prominent results in improving the viscoelastic properties of ordinary bitumen. The effects of SBR modifier influenced significantly the rheological behavior of bitumen by increasing its complex shear modulus (G*) and increasing the resistance of mixture against permanent deformation (Rutting). Despite the advantages of SBR on bitumen performance at high temperatures, it does not show a considerable influence on the intermediate temperature performance of bitumen. In addition, results show that increasing the additive content increases the viscosity of modified bitumen. This in return resists the compactive effort and there will be low stability values and there will be more chances for fatigue cracking.

ABSTRAK

Kajian ini mengkaji sifat-sifat reologi dari pengikat bitumen (asfalt) penusukan gred 60-70 yang diubahsuai dengan bahan tambahan Stirena Butadiena Getah (SBR). SBR adalah elastomer yang merupakan jenis yang penting daripada getah tiruan. Ia adalah kopolimer yang mengandungi stirena sebatian organik dan rantaian butadiena yang membentuk struktur molekulnya. Bitumen adalah bahan likat- kenyal di mana suhu dan kadar permohonan beban mempunyai pengaruh yang besar terhadap prestasi mereka. Sifat yang dinilai termasuk sifat-sifat reologi dari pengikat bitumen yang diubahsuai. Ciri-ciri ini adalah modulus ricih kompleks G* menggunakan Dynamic Ricih Reometer (DSR), penuaan jangka pendek oleh *"Rolling Thin Film Oven Test (RTFOT)"*, penuaan jangka panjang dengan *"Pressure Aging Vessel (PAV)"*, kelikatan oleh *"Rotational Viscometer (RV)"*, penusukan oleh Penetro meter and dan titik lembut oleh Ring dan Ball test. Keputusan yang diperolehi daripada kajian ini menunjukkan pengaruh SBR pada pengikat, dan juga bergantung kepada kuantiti (%) dari bahan tambahan yang digunakan dan ujian suhu. Pengikat telah bercampur dengan pelbagai peratusan daripada SBR pada 1, 2, 3, 4 dan 5% mengikut berat bahan pengikat bitumen. Menggunakan SBR menunjukkan keputusan penting dalam meningkatkan sifat-sifat viskoelastik bitumen biasa. Kesan SBR pengubahsuai mempengaruhi kelakuan reologi bitumen secara ketara dengan meningkatkan modulus ricih kompleks (G*) dan meningkatkan ketahanan campuran terhadap ubah bentuk kekal (aluran). Walaupun kelebihan SBR pada prestasi bitumen pada suhu yang tinggi, ia tidak menunjukkan pengaruh yang besar ke atas prestasi suhu pertengahan bitumen. Di samping itu, keputusan menunjukkan bahawa peningkatan kandungan tambahan meningkatkan kelikatan bitumen yang diubahsuai. Ini sebagai balasan menentang usaha pemadatan dan akan ada nilai kestabilan yang rendah dan akan ada lebih banyak peluang untuk kelesuan retak.

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LIST OF ABBREVIATIONS

SBR	-	Styrene Butadiene Rubber
PE	-	Polyethylene
SBS	-	Styrene Butadiene Styrene
ASTM	-	American Society for Testing and Materials
PMBs	-	Polymer Modified Bitumens
AC	-	Asphaltic Concrete
Cp	-	Centipoise
Dmm	-	Decimillimeter
DSR	-	Direct Shear Rheometer
kPa	-	Kilopascal
HMA	-	Hot Mix Asphalt
OBC	-	Optimum Bitumen Content
BS	-	Britsh Standard
PAV	-	Pressure Aging Vessel
RTFOT	-	Rotating Thin Film Oven Test
^{o}C	-	Centigrade, Celcius

CHAPTER 1

INTRODUCTION

1.1 Background of Study

The general development of any country can be judged from the system of transportation laying that country. Most of the countries in the world underwent a rapid rate of development in every aspect of life that was dominated by the construction boom that started two decades ago. This resulted in increased traffics volume and higher than design load magnitude. These heavy loads coupled with the high ambient temperature, are undoubtedly the primary factors contributing to the development of premature pavement. Damage to the binder and wearing course typically, the pavement distress parameters are broadly classified into rutting, fatigue cracking, low temperature cracking and moisture induced damage. Rutting is due to permanent deformation in the pavement layers. Identification of the road cracks at an early stage is essential as preventive road maintenance and effective remedial measures can be applied before the problem becomes too severe and the pavement fails. The primary reasons for the deteriorated conditions of roads include the increase in the overall traffic, poor asphalt binder quality coming from high-tech refining processes and climatic changes. Improved construction processes will secure the solution to these challenges. It is necessary to understand the fundamental behavior and properties of roads before starting to develop advanced construction processes (Glover, 2007).

To ensure the mixes resist climate and traffic, specifications on paving grade bitumen have grown to be quite severe. The qualities that are required to acquire appropriate bitumen are mainly rheological. First, the bitumen needs to be fluid enough at hot temperature (around 160°C) to become pumpable and workable to permit a homogeneous coating from the aggregates upon mixing. Second, it needs to become stiff enough in the greatest pavement temperature to face up to rutting (around 60°C, based on local climate). Third, it has to remain soft enough in the cheapest pavement temperature to face up to cracking (lower close to -20°C, based on local climate). Each one of these qualities is very opposite, which is therefore hard to obtain bitumen that will work under all possible environments. As a result, different paving grades exist, the much softer being generally appropriate for cold environments and also the harder, for warmer regions. To be able to widen the temperature selection of bitumen, chemicals for example polymers and/or chemicals are progressively used.

The performance of road pavement is determined by the properties of the bitumen, as bitumen is the continuous phase and the only deformable component (Yuonne *et al.*, 2001). And also is a viscoelastic material with suitable rheological properties for traditional paving and roofing applications because of their good adhesion properties to aggregates (González Uranga, 2008). Pavement defects, such as rutting at high temperatures, cracking in low temperatures, are not only due to traffic loads but also to the thermal susceptibility of bitumen (Ruan, 2003). The use of polymer modified bitumen (PMBs) has been studied for a long time. These typically increase the stiffness of the bitumen and improve its temperature susceptibility. The properties of PMBs are dependent on the polymer characteristics, content and bitumen nature, as well as the bleeding process. Elastomers and plastomers are typically used in bitumen modification, such as styrene butadiene rubber (SBR), styrene butadiene styrene tri-block copolymer (SBS) and polyethylene (PE) (Bates *et al.*, 1987).

The science of rheology is only about 70 years of age. It was founded by two scientists namely Professor Marcus Reiner and Professor Eugene Bingham meeting in the late 20s having the same need for describing fluid flow properties. Rheology literally means the study of flow. The mechanical test normally carried out on bitumen would be to determine the consistency from the binder, as it’s been utilized in highway construction (Gandhi *et al.*, 2008). The performance of asphalt pavement is principally controlled by the qualities from the binder, also it exhibits a viscoelastic behavior hence in pavement when uncovered to hot temperature permanent deformation (rutting) happens across the wheel road to the pavement. However, bitumen in pavement at low temperature exhibits brittleness and pavement cracking happens.

Asphalt can be used as road carpeting material around the world (Al-Dubabe *et al.*, 1998). However, because of low supply it has been relatively expensive. The rise in traffic throughout the previous two decades in conjunction with an inadequate amount of maintenance has triggered faster degeneration of road structures in lots of countries (Isacsson *et al.*, 1995). To reduce the degeneration and therefore to improve the long-term sturdiness of the flexible pavement, the asphalt layers ought to be enhanced regarding performance related qualities, for example potential to deal with permanent deformation, low temperature cracking, load-connected fatigue, draining and ageing. Furthermore, for several programs, for example bridges, such as runways and surfaces with high traffic loading, special binders are urgently needed (Isacsson *et al.*, 1995).

However, SBR has been found to be one of the most effective polymer additives. SBR describe families of synthetic rubbers derived from styrene and butadiene (the version developed by Goodyear is called Neolite) (Di Pilla, 2012). These materials have good abrasion resistance and good aging stability. In 2012, more than 5.4 million tons of SBR were processed worldwide. About 50% of car tires are made from various types of SBR. SBR may both affect the initial engineering properties of HMA pavement and increase its service life. However, since the mixing conditions for the bitumen and polymer have considerable effect on the behavior of polymer modified bitumen, it should be determined as the most suitable mixing conditions for bitumen and polymer. However, in a successful polymer modified bitumen modification, the type of polymer, the compability between bitumen and polymer and the amount of polymer to be added to bitumen should be carefully design (Hooleran, 1999). If the consistent mixing time and mixing temperature are not provided for bitumen–modifier mix, modified bitumen cannot exhibit good performance in situ, thus premature failures will occur. In addition, modifier content is also an important factor affecting the performance of the polymer-modified asphalt concretes. Therefore, there are certain recommended mixing time, mixing temperature and modifier content for all the polymers with a trademark.

1.2 Problem statement

Nowadays, we depend on the road to transport us from one place to another place almost every day in our lives. The quality of road of a country determines the level of development of those country possess flexible pavements have to sustain increasingly large traffic loads. When these loads are combined with adverse environmental conditions, in some countries like Pakistan where hot climate is major problem for asphalt concrete road pavement due to overloading and thus the main problem is of rutting and also cracking, however the problem of rutting is at much extent. Due to presence of cracks some problems may occur, e.g. loss of waterproofing, loss of load spreading ability, pumping and loss of fines from the base course, loss of riding quality. Longitudinal deformation in a wheel path, rutting is irregularly occurring in the driving direction. Possible causes are settlement of the sub grade and base course, plastic deformation of bituminous materials (flow) observed longitudinally. It is accelerated by the combined effect of traffic and high temperature and inadequate compaction in surfacing or base, therefore using of SBR in bitumen modification considered as a sustainable technology which transforms an unwanted residue into a new bituminous mixture highly resistant to rutting and fatigue.

In addition, with the warm mix asphalt (WMA) technology it is expected to reduce the temperature requirements while producing the same quality of mix. WMA is a relatively new technology, and there is a need to find the effects of warm asphalt additives on the binders and the mixtures in detail. There are many adverse effect and consequences associated with the production of hot mix asphalt. These include high energy consumption to maintain workable temperatures, and hazardous asphalt fumes that are harmful to the health of the workers at the production plant and during construction. Asphalt mix producers seek environmentally friendly, energy efficient, and worker friendly methods.

1.3 Objectives

The objective of this study is to investigate the effect of using different percentages of SBR on viscosity, penetration and on the rheological properties of asphalt binders.

It is previously known that main problem of asphalt pavement material is rutting and cracking which is resulted from its main property of being high temperature susceptibility. Therefore, the specific objectives are as follows:

- To determine the rheological properties of the modified bitumen containing different percentages of SBR.

- To investigate the long–term and short-term aging performance of modified bitumen incorporating SBR.

1.4 Scope of Study

The type of the binders which used was 60-70 grade bitumen. This research includes physical tests for the viscosity, penetration and softening point for both unmodified and modified bitumen of 60-70 penetration grade. The rheological properties of modified binders help to identify the importance of using modifiers in pavement industries. The rheological tests will be undertaken using a Dynamic Shear Rheometer (DSR) apparatus based on the fundamental of dynamic mechanical analysis. Aging of bitumen was done using the RTFO for short term aging and PAV for long term ageing and effect of ageing on the rheological parameters were studied.

All tests were conducted at Highway Engineering Laboratory in the Faculty of Civil Engineering, Universiti Teknologi Malaysia (UTM).

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