ENGINEERING PROPERTIES OF BITUMINOUS MIXTURE USING KAOLIN AS A MODIFIER

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ABSTRACT

The pavement system plays an important role in the economic and social sectors of a country. Construction of pavement is increasing day by day to cater for the huge traffic volume. Subsequently, it is important to improve the quality of road structure to reduce congestion and disruptions of journeys for road users. Improvements of road pavement using conventional bitumen are inadequate to prevent pavement deterioration. Research has been done on modification of bitumen to address this problem. In this research, kaolin was used for the modification of bitumen to improve the quality of roads. Kaolin was added at an increment of 2%, starting with 0% to 12% by weight of bitumen of PEN 80-90 and 80-100 to analyse the physical and rheological properties of the modified bitumen. Short term aging and long term aging were carried out on the modified bitumen to simulate the condition of aging during production, and after laying of bituminous mixture on roads. Penetration and softening point tests were performed to determine the physical properties. Penetration index was calculated from penetration and softening point tests, which indicated the temperature susceptibility of the modified bitumen. Viscosity and Dynamic Shear Rheometer (DSR) tests were carried out to determine the rheological properties of this bitumen. Complex shear modulus (G*) and phase angle (δ) are the two parameters of DSR. A Marshall test was carried out on the bituminous mixture which was prepared from kaolin modified bitumen PEN 80-100. The engineering properties of the modified bitumen indicated that their physical and rheological properties have improved. The significant effect was that, kaolin reduced penetration depth and increased viscosity of modified bitumen. The modified bitumen has shown better elastic response and stiffness, which indicate a strong correlation of rutting resistance associated with temperature. A higher percentage of kaolin modified bitumen has been shown to be very close to failure criteria of fatigue cracking due to hardness of modified bitumen. Marshall properties of kaolin modified bituminous mixture has a higher stability and lesser deformation. It can be concluded that kaolin modified bitumen improves quality of road pavements where the temperature is high.

ABSTRAK

Sistem jalan raya memainkan peranan penting dalam sektor ekonomi dan sosial kepada sesebuah negara. Pembinaan jalan raya semakin meningkat dari hari ke hari bagi memenuhi keperluan jumlah lalu lintas yang semakin banyak. Oleh itu, adalah penting untuk meningkatkan kualiti struktur jalan raya bagi mengurangkan kesesakan dan gangguan perjalanan bagi pengguna jalan raya. Penambahbaikan turapan jalan dengan menggunakan bitumen konvensional masih lagi belum cukup untuk mengatasi kerosakan jalan. Banyak penyelidikan telah dilakukan untuk pengubahsuaian bitumen bagi mengatasi masalah ini. Dalam kajian ini, kaolin digunakan untuk pengubahsuaian bitumen untuk meningkatkan kualiti jalan. Kaolin ditambah pada kenaikan 2%, bermula dengan 0% hingga 12% bagi berat bitumen PEN 80-90 dan 80-100 untuk menganalisis sifat fizikal dan reologi bitumen yang telah diubahsuai. Penuaan bitumen untuk jangka pendek dan jangka panjang telah dilakukan pada kaolin bitumen yang diubahsuai untuk meniru keadaan penuaan semasa proses penghasilan campuran turapan dan selepas meletakkan campuran turapan di jalan raya. Ujian penusukan dan titik lembut dilakukan untuk menentukan sifat fizikal bitumen. Indeks penusukan dikira daripada ujian penetrasi dan titik lembut, yang menunjukkan kecenderungan suhu bitumen yang diubahsuai. Ujian kelikatan dan Rheometer Ricih Dinamik (DSR) telah dijalankan untuk menentukan sifat reologi kaolin bitumen ini. Modulus ricih kompleks (G*) dan sudut fasa (δ) adalah dua parameter DSR. Ujian Marshall telah dilakukan pada campuran bitumen yang telah tersedia daripada kaolin bitumen PEN 80-100 yang diubahsuai. Ciri kejuruteraan kaolin bitumen yang diubahsuai menunjukkan sifat fizikal dan reologi bertambah baik. Kesan pentingnya ialah kaolin mengurangkan kedalaman penusukan dan meningkatkan kelikatan bitumen yang diubahsuai. Bitumen yang diubahsuai telah menunjukkan tindak balas elastik dan kekakuan yang lebih baik, bilamana hasil ujian menunjukkan rintangan yang kuat dengan ‘aluran’ bila berkadaran dengan suhu. Peratusan yang tinggi pada kaolin bitumen yang diubahsuai menunjukkan ia hampir dekat dengan kriteria kegagalan terhadap retakan disebabkan kekerasan bitumen yang diubahsuai. Ciri-ciri Marshall pada kaolin bitumen yang diubahsuai menunjukkan kestabilan yang lebih tinggi dan ubah bentuk yang lebih rendah. Dapat disimpulkan bahawa bitumen kaolin yang diubahsuai meningkatkan kualiti jalan raya pada suhu tinggi.

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society of Testing and Materials
CEC	Cation exchange capacity
DSR	Dynamic shear rheometer
EVA	Ethylene vinyl acetate
EN	European norms
HDPE	High density polythelene
LDPE	Low density polyethylene
Mt	Montmorillonite
OBC	Optimum bitumen content
OKC	Optimum kaolin content
PMB	Polymer modified bitumen
PI	Penetration index
RTFO	Rolling thin film oven
RV	Rotational viscometer (RV)
RPM	Revolution per minute
RET	Reactive ethylene terpolymer
SBR	Styrene butadiene rubber
SBS	Styrene butadiene styrene
SHRP	Strategic Highway Research Program
SP	Softening point
TEM	Transmission electron microscopy
VFB	Voids filled bitumen
VMA	Voids mineral aggregates
V_b	Bitumen volume
VTM	Voids in total mix

LIST OF SYMBOLS

G*	Complex shear modulus
δ	Phase angle
M_r	Resilient modulus

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

The performance of pavements is mostly influenced by the loading magnitude, configuration and load repetitions by heavy vehicles (Sharad and Gupta, 2015). Road pavement is one of the major infrastructures which plays a vital role for economy, study, security, hospitalization and many other purposes of a country. Government invests lots of money for developing the road network, which is one of major sources of income for the country. The government has to be more concerned with the road sector as it is a major part for developing a country.

Bitumen is a thermoplastic material of hydrocarbons including paraffinic, saturates, aromatics, resins and graphitic bitumenenes. It is widely used as a very effective binder for mineral aggregates to form effective mixture of pavement construction materials. Bitumen is a thermoplastic liquid. At high temperature, it behaves like a viscous liquid and at low temperature behaves like an elastic solid. There is a significant affect on road construction at rainy season of adverse climatic condition. Lack of durability and densification of a layer under repetitive load actions are considered the limitation of long service life for bitumen pavement. Therefore, bitumen pavement shall be achieved a sufficient strength to overcome these limitations (Salleh, 2010). Recently, many additives have been used to improve the physical properties, performance and durability of bitumen. Modified bitumen mitigates the pavement distress and reduces life cycle cost as compared to

unmodified bitumen. The desirable characteristics of modified bitumen are better elastic recovery, a higher softening point, greater viscosity, better cohesive and adhesion strength (Collins *et al*., 1991; Salleh, 2010). Modified bitumen was used to improve the pavement performance, as it can prolong the service life of pavement even with the unexpected volume of traffic. Modified bitumen pavement exhibits greater resistance of rutting, decreases the fatigue crack and temperature susceptibility (Ashok *et al*., 2012).

A road pavement is a structure consisting of superimposed layers of processed materials above the natural soil sub-grade, whose primary function is to distribute the applied vehicle loads to the sub-grade. At ambient temperatures, bitumen behaves as a visco-elastic material providing both stability and flexibility which present as essential properties for long lasting pavements (Golestani *et al*., 2012). However, increasing of traffic volume, heavier and larger truck that are greater than design load on the pavement and increasing of tire pressure contribute to damage of pavement and it will shorten the life span of the pavement. The pavement structure should be able to provide a surface of acceptable riding quality, adequate skid resistance, favourable light reflecting characteristics, and low noise pollution. The ultimate aim is to ensure that the transmitted stresses due to wheel load are sufficiently reduced, so that they will not exceed bearing capacity of the sub-grade. There are two main types of pavement, which are flexible pavement and rigid pavement. This study will focus on flexible pavement.

Flexible pavement consists of series of layers with the highest quality materials at or near the surface of pavement. Flexible pavements are designed to resist fatigue cracking, low temperature cracking, rutting and other temperature distress. The fatigue cracking of flexible pavement is due to horizontal tensile strain at the bottom of the asphaltic concrete. Rutting occurs only on flexible pavement as indicated by permanent deformation or rut depth along wheel load path. Thermal cracking includes both low-temperature cracking and thermal fatigue cracking (Shahbaz *et al*., 2013).

One step ahead is needed to minimize this major problem in road pavement. Bituminous layers should be improved to make it long lasting with slightly maintenance and comfort to the end user. Thus, this study comes out to improve the quality of bitumen by using kaolin as a modifier in bitumen PEN 80-90 and 90-100.

1.2 Problem Statement

The axle weight of heavy vehicles has lead to a dramatic increase in level of stresses exerted on bitumen surface. This sharp increase of stresses is one of the reasons for reducing the service life of unmodified bitumen (Shafii *et al*., 2011). The rutting gets affected with temperature and moisture content, with higher temperature causing more rutting (Shahbaz *et al*., 2013). At high temperature, around 36°C to 41°C, with excessive traffic volume induced the vehicle wheel strip on the road which reduce the life cycle of bitumen (Donald, 1986; Minakshi Singhal *et al*., 2016; Quddus, 2010). In recent years, as the demand for pavement has increased, researchers have focused on production of modified bitumen (Seyed Mojtaba *et al.*, 2015). Overheating reduces the binding properties of bitumen. If the temperature of bituminous mix has been reduced then the compaction will not be proper leading to longitudinal corrugations (Sharad. and Gupta 2015). To combat hot climatic region and cracking in cold climatic region modified bitumen is very convenient for road pavement (Jain *et al*., 2008). Rutting occurs as well as rapid and extreme variations of temperature. The final properties of bituminous mixture are strongly dependent on the quality and rheological properties of the bitumen (Pierre *et al*., 2000). Annually 85% of bitumen production (on the average about 90 million tons of bitumen per year) is used as a binder in road construction. However, oxidized and residual bitumen do not have the necessary properties to meet the modern requirements of pavement (Serhiy *et al*., 2016). To overcome this problem, various researches have been conducted to improve the performance of pavement.

Modifier is very effective for enhancing the storage stability and temperature susceptibility of modified bitumen. In the case of improving storage stability, the biphasic structure of modified bitumen could be destroyed due to excessive interaction between modifiers and bitumen and make the products useless (Zhu and Kringos, 2014). For example, reactive polymer like reactive ethylene terpolymer (RET) has a tendency for inter-chain reaction between modifier and bitumen molecules, which can lead to the nature of chemical formation rather than physical formation (Polacco *et al*., 2006). The chemical formation produced bitumen gel which is completely useless due to insoluble and infusible in nature (Polacco *et al*., 2006).

Montmorillonite and kaolinite clay mineral's have ability to disperse into individual layers at the nanometer level. Fine-tuning their hydrophilic surfaces into hydrophobic ones through ion exchange reactions makes it possible to use them in modified bitumen (Sinha and Okamoto, 2003). Better storage stability and higher viscosity are observed by adding a proper content of hydrophobic clay minerals in polymer modified bitumen (M. Jasso *et al*., 2013). Additionally the ideal exfoliated nature of polymer modified bitumen with this hydrophobic clay mineral is hard to obtain and their use only lead to limited improvements in low-temperature properties, ductility and elastic recovery (Golestani *et al*., 2012). The types and correct proportion of modifier are very important when added into the bitumen to ensure optimum modifier content which has significant strength against physical and functional defects (R. Zhang, 2007). From previous researches, modified bitumen has a limited improvement in elasticity, phase separation problem and relatively high cost. Even popular modifiers have various disadvantages in their application (Zhu and Kringos, 2014). Some problems with bitumen modification are still not well understood. More efforts are expected to be made to promote further development (Collins *et al*., 1991). Therefore, the modified bitumen is important to improve the strength of bitumen and at the same time, it is capable to maintain the physical and rheological properties for a longer service life. Although there are many types of modifiers used to modify the bitumen, they have some limitations. At present, polymer is one of the popular modifier to modify the bitumen (Zhu and Kringos, 2014).

1.3 Objectives

The objectives of this study are to investigate the effect of kaolin as a modifier to modify bitumen for the pavement. This study focused on the following objectives:

i. To determine the engineering properties of modified bitumen at different percentages of kaolin.

ii. To determine the optimum mixing ratio of kaolin for modified bitumen.

The engineering properties of modified bitumen were determined by physical and rheological test. Physical properties can be determined by penetration and softening point test. Rheological properties can be determined by viscosity and dynamic shear rheometer test. The optimum mixing ratio of kaolin content was obtained from Marshall test (Mohamed, 2007).

1.4 Scope of Research

The study focused on the physical and rheological properties of the modified bitumen. The samples of bitumen PEN 80-90 and 80-100 were used for this study. Here the sample of kaolin was used as a modifier. Kaolin is still a new modifier for modification of bitumen. The different percentages of kaolin content were mixed and blended with bitumen. The percentages of kaolin content are 2, 4, 6, 8, 10, and 12% by weight of bitumen. The kaolin modified bitumen was tested for penetration, viscosity, rolling thin film oven, pressure aging vessel and dynamic shear rheometer test. Marshall test was carried out to find out the optimum mixing ratio for kaolin modified bitumen PEN 80-100. All mixing and testing were carried out at highway laboratory in Universiti Teknologi Malaysia (UTM) and Universiti Tun Hussein Onn Malaysia (UTHM).

1.5 Significance of the Study

Different types of modifier have already been used previously to modify bitumen. Although some of those have shown a good result, many researches are still ongoing to find a better modifier. Therefore, the use of kaolin can modify the bitumen in a cost effective manner with long service life despite the heavy traffic load. This study also justifies the kaolin effectiveness for modification of bitumen. The most significant aim of this study is to improve the road performance. The research of this modified bitumen shall be a good lesson for modification of bitumen and this result can be used as valuable resources for further higher studies.

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