EFFECT OF MINERAL FILLERS ON MASTIC AND MIXTURE FOR POROUS ASPHALT

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DEDICATION

"Dedicated to my beloved father, Mohd Shukry and mother, Azizah,
my siblings, Along, Abe, Jie, Ise, and Ada
my nephews, Aqeef and Adeef
my nieces, Dheeya and Aufa
for their love, support, and motivation"

"Also not forgotten to my supervisor,
Dr. Norhidayah Abdul Hassan,
and all my friends
for their assistance and encouragements towards the success of this study.
May Allah bless you all."

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ABSTRACT

Porous asphalt is known to have poor strength and durability due to open nature and large air voids that expose the structure to air, water, and clogging materials. This could lead to stripping and ravelling problems which contribute to rutting potential of porous asphalt. The addition of fillers has been identified to improve the adhesion and cohesion properties by stiffening the asphalt binder and enhancing the bond strength between binder-aggregate. This study aims to investigate the effect of different filler types on the rheological properties of mastics and performances of porous asphalt. Hydrated lime, cement, and diatomite with content of 2% were used as fillers. The morphology and chemical composition of fillers were identified using a Field Emission Scanning Electron Microscopy (FESEM) and Energy Dispersive X-ray (EDX) analysis. Dynamic Shear Rheometer (DSR) was used to investigate the rheological properties of mastics through frequency sweep and Multiple Stress Creep Recovery (MSCR) tests. DSR results indicated that the use of filler increases the stiffness of mastics. The MSCR test showed that hydrated lime and diatomite mastics exhibit the lowest non-recoverable compliance and high recovery compared to original PG 76 binder and cement mastic. The performances of porous asphalt were evaluated using permeability, abrasion loss, resilient modulus, and indirect tensile strength tests. All mixtures were found to show high permeability rate between 0.276 and 0.250 cm/s. Mixtures with hydrated lime showed lower abrasion loss of 21.5% compared to mixtures with cement and diatomite. In addition, the use of diatomite increases resistance of the mixtures to rutting and moisture damage compared to other fillers as shown by the enhanced resilient modulus and indirect tensile strength.

ABSTRAK

Asfalt berliang diketahui mempunyai kekuatan dan ketahanan yang kurang disebabkan sifat terbuka serta lompang udara besar yang mendedahkan struktur itu kepada udara, air, dan bahan-bahan tersumbat. Hal ini membawa kepada masalah pelucutan dan pengikisan yang menyumbang kepada potensi aluran dalam asfalt berliang. Penambahan pengisi dikenal pasti dapat meningkatkan ciri-ciri lekatan dan lekitan dengan mengukuhkan pengikat asfalt dan meningkatkan kekuatan ikatan antara pengikat-agregat. Kajian ini bertujuan untuk mengkaji kesan jenis pengisi yang berbeza terhadap sifat-sifat reologi mastik dan prestasi asfalt berliang. Kapur terhidrat, simen, dan diatomite dengan kandungan 2% telah digunakan sebagai pengisi. Ciri-ciri morfologi dan komposisi kimia pengisi telah dikenal pasti dengan menggunakan *Field Emision Scanning Electron Microscopy* (*FESEM*) dan analisis *Energy Dispersive X-ray* (*EDX*). *Dynamic Shear Rheometer* (*DSR*) telah digunakan untuk mengkaji sifat-sifat reologi mastik melalui ujian *frequency sweep* dan *Multiple Stress Creep Recovery* (*MSCR*). Keputusan DSR menunjukkan bahawa penggunaan pengisi meningkatkan kekukuhan mastik. Hasil ujian MSCR menunjukkan mastik kapur terhidrat dan diatomite mempamerkan *non-recoverable compliance* paling rendah dan *recovery* yang tinggi berbanding pengikat asal PG 76 dan mastik simen. Prestasi asfalt berliang telah dinilai melalui ujian kebolehtelapan, kehilangan lelasan, daya tahan modulus, dan kekuatan tegangan tidak langsung. Semua campuran didapati menunjukkan kadar kebolehtelapan yang tinggi di antara 0.276 dan 0.250 cm/s. Campuran dengan kapur terhidrat menunjukkan kehilangan lelasan lebih rendah iaitu 21.5% berbanding campuran dengan diatomite dan simen. Tambahan pula, penggunaan diatomite meningkatkan rintangan campuran terhadap aluran dan kerosakan akibat lembapan berbanding pengisi lain seperti yang ditunjukkan oleh peningkatan dalam daya tahan modulus dan kekuatan tegangan tidak langsung.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS/SYMBOLS

FESEM	-	Field Emission Scanning Electron Microscopy
EDX	-	Energy Dispersive X-Ray
DSR	-	Dynamic Shear Rheometer
MSCR	-	Multiple Stress Creep Recovery
JKR	-	Jabatan Kerja Raya
HMA	-	Hot Mix Asphalt
PFC	-	Permeable Friction Course
OGFC	-	Open Graded Friction Course
NCAT	-	National Centre for Asphalt Technology
SGC	-	Superpave Gyratory Compactor
OPC	-	Ordinary Portland Cement
PMD	-	Pavement Modifier
AASHTO	-	American Association of State Highway and Transportation Officials
ITS	-	Indirect Tensile Strength
TSR	-	Tensile Strength Ratio
SHRP	-	Strategic Highway Research Program
NCHRP	-	National Cooperative Highway Research Program
SBS	-	Styrene-Butadiene-Styrene
RTFOT	-	Rolling Thin Film Oven Test
PAV	-	Pressure Aging Vessel
DE	-	Diatomaceous Earth
SMA	-	Stone Mastic Asphalt
PSA	-	Periwinkle Shell Ash

ASTM	-	American Society for Testing and Materials
TMD	-	Theoretical maximum density
DMA	-	Dynamic Mechanical Analysis
BBR	-	Bending Beam Rheometer
FTIR	-	Fourier Transform Infrared
ESALs	-	Equivalent Single Axle Loads
ANOVA	-	Analysis of Variance
G^*	-	Complex shear modulus
G'	-	Storage modulus
G''	-	Loss modulus
δ	-	Phase angle
γ	-	Shear strain
τ	-	Shear stress
ω	-	Radian frequency
T_{ref}	-	Reference temperature
a_t	-	Shifting factor
f	-	Loading frequency in hertz
J_{nr}	-	Non-recoverable creep compliance
R	-	Percent recovery
G_{mm}	-	Theoretical maximum density
G_{se}	-	Effective specific gravity
G_{mb}	-	Bulk specific gravity
k	-	Coefficient of water permeability
S	-	Degree of saturation

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background Study

Porous asphalt is an innovative road surfacing technology that is widely used throughout the world. It is a special-purpose wearing course and laid on impermeable asphalt surfaces to improve road safety especially during wet weather. The ability of porous asphalt or permeable friction course to quickly permeate water from the surface has been proven to provide numerous benefits in terms of safety, economy, and the environment. Porous asphalt is widely used in Europe to improve riding quality and visibility in wet weather conditions and reduce noise from highway traffic. Other benefits of porous asphalt include reduced splash and spray, improved skid resistance, minimized glare effect, and reduced hydroplaning (Alvarez *et al*., 2010).

Despite its benefits, the performance life of porous asphalt pavement is affected in terms of functionality (noise reduction and drainage capability) and durability (resistance to ravelling, rutting and cracking) (Liu *et al*., 2010). The lifespan of a porous surface is reported to be shorter than conventional asphalt surfaces due to deterioration from runoff, air infiltration, stripping, oxidation, and binder hardening (Scholz and Grabowiecki, 2007). One of the most important concerns of porous asphalt performance is durability. The open nature of porous asphalt is adversely affected by stresses generated from traffic loads, and the oxidation process of the binder is accelerated by high exposure to water and air. The presence of water flow through the interconnected voids within porous asphalt leads to moisture-related damage that contributes to premature failure. According to Airey *et al*. (2008), moisture damage is defined as loss of strength, stiffness, and durability in an asphalt mixture caused by the failure of the adhesive bond between the aggregate and binder or a loss of cohesion in the asphalt-filler mastic due to the presence of water in the asphalt mixture. Some studies have demonstrated that moisture reduces asphalt-filler mastic stiffness and weakens the aggregate-mastic bond (Kim *et al*., 2008; Little and Jones, 2003). Moisture damage in porous asphalt commonly results in pavement failure such as stripping and ravelling.

Stripping is the most common problem in asphalt pavement which results in the separation of asphalt binder and aggregate due to the weakening of the bond between aggregate surface and asphalt binder in the presence of moisture (Mehrara and Khodaii, 2013). Ravelling is a distress manifestation caused by stripping and is identified by the dislodgement of aggregate particles from the surface of the pavement. This form of distress is related to the properties of asphalt-filler mastic and the bonding interaction of aggregate-mastic in asphalt mixtures (Aman and Hamzah, 2014). Recently, many types of additives have been used as mineral filler to improve the performance of asphalt mixtures against various distresses (Lesueur *et al*., 2012; Cong *et al*., 2012; Liao *et al*., 2013). The addition of fillers in asphalt mixtures improve cohesion and adhesion by stiffening the asphalt binder and improving mixture strength. Filler is defined as a fine material that can fit through a 0.075 mm sieve that when mixed with asphalt binder, forms a high consistency matrix called an asphalt-filler mastic that binds the aggregate particles together (Chen, 1997). According to Wang *et al.* (2011), differences in the composition and physical properties of mineral fillers could affect the rheological properties of asphalt-filler mastics and the performance of asphalt mixtures due to the physical-chemical reaction between fillers and asphalt binders. Therefore, this study evaluates the effect of mineral fillers on the properties of asphalt-filler mastics and the performance of porous asphalt mixtures.

1.2 Problem Statement

Poor durability of porous asphalt is influenced by air, temperature, moisture, and clogging materials. Porous asphalt on the pavement surface, when exposed to high temperatures, causes an increase in oxidation rates that leads to the rapid aging of the binder. The open structure and high permeability of porous asphalt exposes a large surface area to the effects of air and water, which provides oxygen to the binder and accelerates the oxidation rate, effecting the coating properties of the binder. The clogging materials consist of contaminants that accumulate within voids and disturb the bonding between aggregate and binder. These factors cause a loss of bonding in aggregate-binder systems, which leads to adhesive and cohesive failures in porous asphalt. Eventually, these failures increase the potential of aggregate stripping and rapidly cause severe degradation of the wearing surface (ravelling), leading to pothole formation (Kringos and Scarpas, 2008).

In Malaysia, porous asphalt is used as an alternative pavement to reduce traffic accidents and offer better road safety during wet weather conditions. Malaysia is a tropical country which experiences hot and humid weather with high rainfall intensity throughout the year, exposing porous structures to water-related problems. Stripping occurs when an aggregate surface is in contact with water, affecting its adhesion to the asphalt binder and its susceptibility to moisture damage. Besides climatic factors, Malaysia has high traffic impact stress due to tremendous infrastructure development. The stresses generated by traffic loads have a profound effect on the durability of porous asphalt layers due to its open structure.

In order to improve the durability of porous asphalt against pavement distress, mineral fillers are commonly used. Some paving technologists reported that fillers play a dual function in paving mixtures by acting as a mineral aggregate to fill voids and producing contact points between coarser aggregate particles to strengthen the mixture. The other function of filler is to produce a binder with stiffer consistency called an asphalt-filler mastic that binds aggregate particles together (Chen *et al.*, 2008). Therefore, there is a need to study the rheological behaviour of asphalt-filler mastics since filler affects the physical-chemical interaction between fillers and asphalt binders. In addition, the influence of filler types and their properties on porous asphalt mixture performance should be quantitatively studied.

1.3 Aim and Objectives

This study presents a laboratory investigation on the effects of various mineral fillers on porous asphalt performance. The objectives are as follows:

i. To characterise the morphology and chemical composition of hydrated lime, cement, and diatomite as mineral fillers.
ii. To evaluate the rheological properties of asphalt-filler mastics for different mineral fillers.
iii. To evaluate the properties of porous asphalt mixtures with different mineral fillers using laboratory performance tests.

1.4 Scope of Study

Three types of mineral filler namely hydrated lime, cement, and diatomite which passing through a 75 µm sieve size were used to produce asphalt-filler mastics and porous asphalt mixtures. Polymer modified binder, PG 76 was chosen as a base binder for sample preparation. This study consists of an evaluation of the properties of asphalt-filler mastics and the performance of porous asphalt mixtures.

In preparing asphalt-filler mastics for rheological testing, filler content selected was 30% by mass of mastic for all fillers. However, since the specific gravity of fillers differ from one another, filler content by volume of mastic was taken into account for the modification. Thus, the modification of original PG 76 binder with filler contents by volume for hydrated lime, cement, and diatomite were 12, 17, and 14% respectively. The rheological properties of asphalt-filler mastic were evaluated using frequency sweep tests and Multiple Stress Creep Recovery (MSCR) using Dynamic Shear Rheometer (DSR).

Meanwhile, porous asphalt compacted samples were prepared using the Superpave Gyratory Compactor (SGC) for a target air void content of 21±1%. Aggregate gradation Grading B was selected in accordance to JKR specifications (JKR, 2008) for porous asphalt mixtures. During sample preparation, filler content of 2% of the total aggregate weight was used for all mixture design. The performance of porous asphalt mixtures was evaluated using the permeability, abrasion loss, resilient modulus, and indirect tensile strength tests.

1.5 Significance of Study

Hot mix asphalt (HMA) is considered a mixture of mastic-coated aggregate rather than a pure asphalt-coated aggregate. This means that the use of filler has been gaining attention in the asphalt industry to produce good mix designs and high performance asphalt mixtures. This study investigates the functions of fillers in asphalt paving mixtures. In addition, this study provides information on the effect of different types of fillers in porous asphalt mixtures. Therefore, the characterisation of the rheological properties of asphalt-filler mastics is essential to understand the performance of asphalt mixtures in porous asphalt. Besides, detailed properties for porous asphalt are characterised in terms of durability. It is expected that diatomite is a potential paving material and should be taken into consideration in future studies on more durable pavements or as an alternative material for use in pavement construction.

1.6 Thesis Outline

This thesis consists of six chapters and can be summarised as follows:

i. Chapter 1 provides a study overview, study motivations, research objectives, and study significance.
ii. Chapter 2 presents a literature review of porous asphalt mixtures including the properties of porous asphalt, problems in using porous asphalt mixtures, and several tests used to evaluate their performance. Additionally, this chapter provides filler details as well as filler applications in asphalt-filler mastics and asphalt mixtures. This chapter explains the details of dynamic mechanical analysis using a DSR and provides various forms of data presentation to interpret the viscoelastic properties of asphaltic materials.
iii. Chapter 3 explains the employed experimental programme, materials characterisation, sample preparation methods, and laboratory testing procedures.
iv. Chapter 4 reports on the rheological properties of asphalt-filler mastics using the frequency sweep and creep recovery tests.
v. Chapter 5 presents the investigation results for different filler types using permeability, abrasion loss, resilient modulus, and indirect tensile strength tests.
vi. In Chapter 6, the study is concluded with recommendations for subsequent research.

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