PERFORMANCE OF RUBBERIZED MODIFIED ASPHALT MIXUTRES INCORPORATING SILANE ADDITIVE ZYCOTHERM

LIM WEE ZHENG

SCHOOL OF CIVIL ENGINEERING
UNIVERSITI SAINS MALAYSIA
2018

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By

LIM WEE ZHENG

This dissertation is submitted to

UNIVERSITI SAINS MALAYSIA

As partial fulfilment of requirement for the degree of

BACHELOR OF ENGINEERING (HONS.)
(CIVIL ENGINEERING)

School of Civil Engineering,
Universiti Sains Malaysia

June 2018

SCHOOL OF CIVIL ENGINEERING
ACADEMIC SESSION 2017/2018

FINAL YEAR PROJECT EAA492/6
DISSERTATION ENDORSEMENT FORM

Title:

Name of Student:

I hereby declare that all corrections and comments made by the supervisor(s)and examiner have been taken into consideration and rectified accordingly.

Signature: Approved by:

_______________________ _______________________

(Signature of Supervisor)

Date : Name of Supervisor :

Date :

Approved by:

____

(Signature of Examiner)

Name of Examiner :

Date :

ACKNOWLEDGEMENT

First and foremost. I wish to express my profound gratitude to my supervisor, Dr. Mohd Rosli Mohd Hasan for his kind help, close supervision, constant guidance in the theoretical formulations as well as in the experimental aspects of this research work from its very early conceptual stages until its completion.

Furthermore, I would like to extend my gratitude to the technicians of Highway Engineering Laboratory, University Sains Malaysia, Mr. Mohd Fouzi bin Ali and Mr. Zulhairi bin Ariffin and the technician of Structural Engineering Laboratory, Mr. Abdullah Md Nanyan for their cooperation and guidance in this research. Special thanks to Teh Sek Yee and Tan Shin Ru for their encouragement, insightful comments, and valuable feedback on my research.

This project was supported through USM Short Term Research Grant (304/PAWAM/60313048). I would like to thank the aggregate and bitumen suppliers, KUAD Sdn Bhd and Kamunting Premix Plan Sdn Bhd respectively.

Finally, thank you simply does not express my appreciation to my family for their constant support in all I do. This thesis would not have been possible without their love and support.

ABSTRAK

Kajian ini dijalankan bagi menilai prestasi campuran asfalt terubahsuai getah yang digabungkan dengan bahan tambahan Zycotherm. Ciri-ciri perkhidmatan campuran asfalt terubahsuai getah dinilai berdasarkan indeks kebolehkerjaan dan indeks pemadatan tenaga untuk menunjukkan kemudahan campuran asfalt untuk dihamparkan, dikendalikan dan dipadatkan. Selain itu, sifat kejuruteraan campuran asfalt telah dinilai dari segi kekuatan tegangan tidak, ujian kebingkasan, ubah bentuk kekal, rintangan lembapan dan kekuatan ricih. Campuran asfalt telah disediakan dan dipadatkan pada lompang udara 4% untuk mensimulasikan keadaan sebenar ditapak. Sedangkan rintangan lembapan diuji dengan menggunakan campuran asfalt pada 7% lompang udara. Berdasarkan dapatan, campuran asfalt terubahsuai mempunyai prestasi yang lebih baik dari segi sifat-sifat kekuatan tegangan, ubah bentuk kekal, ujian kebingkasan, kekuatan ricih dan rintangan lembapan. Daripada indeks kebolehkerjaan dan tenaga pemadatan, campuran asfalt terubahsuai adalah lebih baik daripada campuran asfalt diubahsuai. Prestasi campuran asfalt umumnya mengutamakan kepada campuran asfalt tidak terubahsuai. Oleh itu, campuran asfalt terubahsuai mempunyai prestasi yang lebih baik terhadap trafik yang tinggi intensiti dan gandar beban.

ABSTRACT

The purpose of this study is to evaluate the performance of rubber modified asphalt mixture incorporating silane additive Zycotherm. The service characteristics of rubber modified asphalt mixture were evaluated using workability index and compaction energy index to indicate the ease of asphalt mixture to be placed, handling and compacted. Besides, the engineering properties of asphalt mixture were evaluated in terms of Indirect Tensile Strength (ITS), Resilient Modulus, permanent deformation, moisture susceptibility resistance and Leutner Shear (LS) Test. The asphalt mixture was prepared and compacted at 4 ± 1 % air voids which according to the Standard of Public Work Department of Malaysia's (PDW), whereas the moisture susceptibility resistance was tested with using asphalt mixture compacted at 7 ± 1 % air voids. Based on the results, it was found that crumb rubber modified asphalt mixtures have a better performance in terms its tensile properties, permanent deformation, resilient modulus, shear resistance and moisture resistance. From the workability and compaction energy index, unmodified asphalt mixture is better than modified asphalt mixture. The asphalt mixture performance generally favours to the modified asphalt mixture. Therefore, modified asphalt mixture has better performance against the high traffic intensity and axle loads.

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LIST OF ABBREVIATIONS

PMA	**P**olymer **M**odified **A**sphalt
NR	**N**atural **R**ubber
BR	**B**utadiene **R**ubber
SBR	**S**tyrene **B**utadiene **R**ubber
EPM	**E**thylene-propylene **M**onomers
TPEs	**T**hermoplastic **E**lastomers
PE	**P**olyethylene
PP	**P**olypropylene
EVA	**E**thylene **V**inyl **A**cetate
DAT	**D**ispersed **A**sphalt **T**echnology
HMA	**H**ot **M**ix **A**sphalt
PWD	**P**ublic **W**orks **D**epartment
CR	**C**rumb **R**ubber
SGC	**S**ervopac **G**yratory **C**ompactor
VMA	**V**oids in **M**ineral **A**ggregate
CEI	**C**ompaction **E**nergy **I**ndex
WI	**W**orkability **I**ndex
ITS	**I**ndirect **T**ensile **S**trength
UTM	**U**niversal **T**esting **M**achine
TSR	**T**ensile **S**trength **R**atio
LS	**L**eutner **S**hear
LVDT	**L**inear **V**ariable **D**ifferential **T**ransducer
ASTM	**A**merican **S**ociety for **T**esting and **M**aterials

AASTHO	**A**merican **A**ssociation of **S**tate **H**ighway and **T**ransportation **O**fficials
SSD	**S**aturated **S**urface **D**ried

NOMENCLATURES

G_{mm}	Theoretical Specific Gravity
G_{mb}	Bulk Specific Gravity
AV	Air Voids
Si-O-Si	Siloxane
V	Volume of the Specimen
H_2O	Water Molecules

CHAPTER 1

INTRODUCTION

1.1 Background

In Malaysia, asphalt pavement was introduced to ensure the safety and good riding experience for the road users while driving. However, the increase in traffic intensity and axle loads have led to high tendency of pavement failure and brought higher demand for a better highway system in varying climate environments. These pavement failures of road such as permanent deformation, fatigue cracking, pothole and rutting. For instance, rutting is the surface depression of road which caused by progressive accumulation of permanent deformation of each layer of pavement structure under repetitive loading (Balghunaim et al., 1988). Pavement distress will cause the unnecessary delay of traffic flow, reduce the lifespan of pavement and increased the maintenance cost. To tackle the problem, designers should consider three fundamental elements which include environmental factors, traffic flow and asphalt mixture material (Mahrez, 1999).

Generally, pavement distress is related to asphalt binder and asphalt mixture properties (Marin, 2013). Asphalt binder is responsible to hold the aggregates firmly and act as sealant against water. For instance, rutting and cracking are most commonly caused by the rheological properties of the aged asphalt binder (Zhang et al., 2017). Different kind of polymer modified asphalt mixture such as crumb rubber and latex incorporated with silane additive Zycotherm were investigated to overcome the pavement distress (Bala et al., 2018).

Asphalt binder is an inexpensive and waterproof thermoplastic adhesive material which holds and binds the aggregates together. It also acts as the glue to hold and binds the aggregate together. Rubber modified asphalt is the incorporation of bitumen with polymer by mechanical mixing or chemical reaction (Zhu et al., 2014). According to (Chen et al., 2018) , the presence of polymer in polymer modified asphalt mixture improves the performance of asphalt pavement which subject to heavy traffic loading. The modified asphalt mixture able to enhance the mechanical performance and durability of asphalt binder such as viscosity and ductility of the binder (Liu et al., 2018). Therefore, rubber modified asphalt mixture decreases traffic noise, improves pavement performance and reduce the maintenance cost needed (Xiao et al., 2009). This is because presence of polymer improves the properties of bitumen such as increases the stiffness at higher temperature, improves the cracking resistance at low temperature, improves adhesion properties of bitumen into aggregate and better moisture resistance or longer fatigue life (Tayfur et al., 2007). As a result, rubber modified asphalt mixture is able to enhance the performance of asphalt mixture.

The service characteristic and performance of modified aspahalt mixture are affected by the method of manufacturing process. The manufacturing process of crumb rubber modified asphalt can be divided into two methods which are wet process and dry process (Ding et al., 2017). In wet process, the crumb rubber was pre-blended with asphalt binder, followed by mixing with aggregate. It is also applicable for the production of latex modified asphalt mixture. On the other hand, the crumb rubber is first mixed with the aggregate as another material before it was added into the mix. This process is not suitable for producing latex modified asphalt mixture. The dry process is less popular because it produces inconsistent and unsatisfied results which mainly due to poor interaction between the crumb rubber and bitumen (Moreno et al., 2012).

This study focuses on the service characteristics and performance of crumb rubber and latex modified asphalt mixture incorporating silane additive Zycotherm. The service characteristics refer to workability index and compaction energy index. The performance and engineering properties of asphalt mixture were investigated in terms of aggregate bonding, resistance properties, permanent deformation, elastic properties and tensile properties. At the end of the study, crumb rubber and latex modified asphalt mixtures can perform better on the road of higher traffic intensity and axle road compared with conventional asphalt mixture.

1.2 Problem Statement

Highway pavement distress is a serious problem that caused unnecessary delay in traffic flow, high maintenance cost and endanger the road users. A variety of factors contribute to pavement distress such as applied loading on pavements are larger than the strength of the material, low quality of construction material and poor supervision of construction work. The crumb rubber or latex modified asphalt mixture is suggested because it may improve the performance of asphalt mixture. Therefore, it is necessary to evaluate the performance of crumb rubber and latex modified asphalt mixture in terms of workability, compactability, tensile properties, elastic properties, bonding between the aggregate and resistance against moisture damage. Prior to enhance the service characteristic of asphalt mixture, the surfactant of Zycotherm has been used to reduce the surface tension of binder, improves bonding between materials and structural integrity. To understand the relationship between the modified asphalt towards the performance of asphalt mixture, experimental works have been done in the laboratory.

1.3 Objectives

The aim of this research is to evaluate the performance of rubber modified asphalt mixture incorporating additive silane Zycotherm. The main objectives of this research are:

- To evaluate the workability index and compaction energy index of rubber modified asphalt mixtures.
- To determine the physical and mechanical behaviour of rubber modified asphalt mixtures.
- To compare the performance of both latex and crumb rubber modified mixtures with the presence of silane additive Zycotherm.

1.4 Significant of Study

Scrap tires have been a serious issue as it occupied a large scale of landfill space. This causes various environmental issues such as land and air pollution. In this study, the scrap tires and latex are recycled and utilized in the asphalt mixture which has great potential to lower the environmental impact and boost valorization of waste products and natural resources. As a result, the study of rubber modified asphalt mixture acts as a stepping stone to construct the most economical and sustainable road pavement with high strength.

Apart from that, the premature failure can be reduced by using the modified asphalt mixture as highway pavements. The performance of modified asphalt mixture depends on the amount of modifier added and type of modifier used. Therefore, it is necessary to investigate the engineering properties of modified asphalt mixture with different contents of modifier and different types of modifier additive. Therefore, the outcomes of the research are important to provide good reference to characterize the effect of different types of rubber with different content.

1.5 Scope of work

The modified asphalt mixture incorporated with 0.1 % of Zycotherm was prepared by using crumb rubber and latex as an additive modifier. Asphalt binder grade 60/70 is adopted for this research. Crumb rubber and latex as a modifier for asphalt mixture was applied at 5 ± 1 % and 10 ± 1 % by the weight of asphalt binder at different mixing and compaction temperatures. The Zycotherm surfactants at 0.1 % of asphalt binder mass composition is used to promote the adhesion and mixing properties of the asphalt mixture. Mixing temperature used for modified asphalt mixture is at 160 °C, whereas for compaction process is 150 °C.

The specimens were produced at two air voids which were 4 ± 1 % and 7 ± 1 % air voids. The specimens at 4 ± 1 % air voids were tested for resilient modulus, indirect tensile, dynamic creep and leutner shear. On the other hand, the 7 ± 1 % air voids specimen was used to determine the moisture susceptibility of asphalt mixture by using modified lottman method.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Asphalt binder is used to hold and bind aggregates to form the asphalt mixture. Pavement distress in Malaysia has caused unnecessary delay in traffic flow and threaten the road users. For example, cracking, pothole, and permanent deformation are common on the roads in Malaysia. Therefore, modified asphalt binder is introduced to improve the bonding, interaction, and coating of the asphalt binder to aggregate in asphalt mixture. Modified asphalt mixture can reduce traffic noise, improves pavement performance and reduces the maintenance cost needed. The modified asphalt mixture increases the viscosity and softening point of the asphalt binder. Thus, by incorporating the anti-stripping agent, it can reduce the free surface energy of the binder. As a result, it promotes the adhesion and mixing properties of the asphalt binder when mixing with aggregate.

This chapter presents the published literature that had been referred in this work. Firstly, asphalt modification where the virgin binder is mix with the modifier enhances the physical properties of the binder. The modifiers are categorized into elastomer and plastomer. The rubberized modified asphalt mixture has increased the mechanical properties such as tensile properties and resilient modulus. This research mainly focuses on the crumb rubber and latex modified asphalt mixture. The incorporating of anti-stripping agent of Zycotherm reduces the free surface energy of the binder. Examples of pavement distress are also discussed in this chapter followed by the effect of rubber and anti-stripping agent incorporate in asphalt mixture. The asphalt mixture performances were evaluated in term of tensile properties, resistance of moisture damage, resilient modulus, permanent deformation and shear resistance.

2.2 Asphalt Modification

Bitumen is a dark brown to black cementitious substances, natural or manufactured, composed principally of high molecular weight hydrocarbon of which asphalts, tars, pitches and asphaltites (ASTM D8, 2002). The asphalt binder is responsible to coat the aggregates and hold it together to form asphalt mixture. Approximately, 85 % of bitumen produced are used as binder in road pavement (Khan and Rahman, 2015). Polymer modified asphalt (PMA) binder is the asphalt incorporate with polymer to mitigate the major causes of asphalt pavement failure such as fatigue cracking and permanent deformation (Chen et al., 2002). The polymers that are capable to be added into asphalt binder are classified into two categories, which are elastomer and plastomer. The elastomer enhances the strength of asphalt mixture at high temperatures, as well as elasticity at low temperature, whereas plastomer can only enhance the strength of asphalt mixture but not elasticity (Illinois DOT, 2005). Modification of asphalt binder with polymeric materials or rubber powder are the most common and popular method to improve the performance of asphalt binder against pavement distresses (Nazari et al., 2018).

When the virgin binder is blended with polymer, the polymer strands absorb part of the low molecular weight oil fraction of the virgin asphalt and become swollen. The polarity of the polymer can enhance its solubility and compatibility with base bitumen (Izquierdo et al., 2012). This enhances the consistency of the binder and decreases oxidative aging (Polacco et al., 2005). When the virgin binder is rich with polymer, it become a continuing phase which all the swollen phase are connected and form a three-dimensional network (Kim, 2010). The three-dimensional network gives the physical properties like elasticity, plasticity, and elongation to asphalt binder (Wekumbra et al., 2007). Generally, modification asphalt binders increase the viscosity of binder and tend to improve the binder coating on aggregate and hold the aggregates more firmly (Illinois DOT, 2005).

2.2.1 Elastomer

An elastomer is a polymer with viscoelastic properties and very weak inter-molecular forces with low Young's modulus and high failure strain (De et al., 2017). Elastomer also names as a hyper elastic material which refers to material that can experience a large stain which is recoverable (Rama Mohan Rao et al., 2018). Each monomer connects to form a compound of elastomer polymer which mainly contains several elements such as carbon, hydrogen, oxygen, and silicon. The polymer chains are held together by a weak intermolecular bond which permit the polymer to stretch in response to macroscopic stresses (Gent et al., 2017). Therefore, elastomer is commonly employed in various applications such as in films, dampers, and adhesive (Delpech and Coutinho, 2000). The most common elastomer materials are cis-polyisoprene (natural rubber, NR), cis-polybutadiene (butadiene rubber, BR), styrene-butadiene rubber (SBR) and ethylene-propylene monomers (EPM).

The elastomers are classified according to its similarity of properties and applications. Polyisoprene has the longest history among the elastomers. This polymer constituent of NR which is made from milky latex of various trees is important in the manufacturing of tyres and gloves. NR is one of the elastomers prepared through chemical cross-linking process (Gopalan Nair and Dufresne, 2003). Physical cross-links are the formation through intermolecular interaction such as hydrogen bonding, ionic bonding and metal-ligand coordination (Kajita et al., 2017).

According to Kajita et al., (2017), thermoplastic elastomers (TPEs) are elastomeric materials which behave like both hard-polymeric component and soft polymeric components at ambient temperature because they can flow when the hard segments become molten at high temperature. Polyurethane and ABA triblock copolymer are the most famous TPEs.

2.2.2 Plastomer

Plastomer is the polymer material which have the behaviours of plastic. Besides, plastomer is formed from ethylene-alpha-olefin copolymers that are made from single site metallocene catalyst using a variety of polymerization processes (Thomas., 2001). Plastic polymer is composed of long-chain crosslinked molecules. Polyolefinic plastomers such as polyethylene (PE), polypropylene (PP) and ethyl vinyl acetate (EVA) are characterized by a rigid dimensional network that quickly exhibit strength under loading but may fracture under strain (Cardone et al., 2016).

The work by Brown et al., (2009) presented the use of plastomer in asphalt modification resulted in a significant increase in pavement stiffness and enhance the resistance against the permanent deformation. Plastomer and bitumen which were added directly to the aggregates at the same time reduced the interaction between bitumen and aggregates. This rubber modified asphalt mixture production, namely dry process. This causes inconsistent and unsatisfied result. Therefore, bitumen from dry process is not truly a modified polymer (Earnest, 2015).

2.3 Modification of Asphalt Mix Using Rubber

The use of rubber modified asphalt mixture in road pavement has been growing rapidly to overcome the problem of pavement distress (Al-Mansob et al., 2014). Sengoz and Isikyakar, (2008) stated that the research regarding polymer-modified asphalt been dramatically increased. The application of rubber modified asphalt improves the performance of asphalt mixture and service life of road surface. This is because it improves the bitumen properties such as elasticity, cohesion, stiffness, and adhesion. Pavement distress such as rutting, fatigue and thermal cracking happen mostly due to excessive traffic loads and adverse condition (Geckil and Seloglu, 2018). Therefore, rubber modified asphalt mixture can improve the resistance against strains such as rutting, fatigue cracking, and permanent deformation.

According to Yusoff et al., (2014), the modifiers of rubber modified asphalt mixture are categorized into naturally occurring materials, an industrial by-product, and waste materials. For example, crumb rubber, natural rubber latex, nano silica fume and Styrene-butadiene rubber are the modifier of rubber modified asphalt mixture. In United Kingdom, the first polymer used was natural polymer latex rubber in the middle of the 1800s (Chong et al., 2005). The rubber modified asphalt mixture becomes more stable and stiffer at high temperature and more flexible at low temperature which endures fatigue and thermal cracking (Brule et al., 1988). According to Lu et al., (1999), the performance of rubber modified asphalt mixture depends on factors such as polymer characteristics, polymer content and nature of asphalts. Hence, the rubber modified asphalt mixture will not only improve the performance of asphalt mixture but also economically reduce the maintenance cost.

2.3.1 Application of Crumb Rubber

With the rapid development of automobile industries and increasing of vehicles annually, over 65 million scrap tires have been produced every year in China and number of scrap tires has been increasing at a rate of 20% annually which exerts a great pressure towards the environment (Wang et al., 2013). Thus, recycling and reusing of crumb rubber produced from automotive and truck scrap tyres have become significantly important to the environment (Presti, 2013). Crumb rubber is manufactured from two primary feedstock which are tire buffing, a by-product of tire rethreading and scrap tire rubber. According to ASTM, (2001) crumb rubber is produced by reducing the size of scrap tire down to 40 mesh particles from 3/8" and removing 99 % of steel and fabric.

Nowadays, the construction and building material industries are focusing on efficiently use of renewable materials and adaption towards green environment. Crumb rubber is widely used in fields of building construction, road construction and underground construction. According to Song et al., (2018), the crumb rubber particles can effectively combine with cement and sand to form crumb rubber mortars. This is because the crumb rubber particle improves the physical and mechanical properties of mortar and improve its ductility and compressive deformation capacity. Furthermore, crumb rubber mortars have been used as structural material to enhance the dynamic performance and seismic performance of concrete structure (Waldron et al., 2005).

In road construction, crumb rubber is employed to produce modified asphalt mixture. The crumb rubber modified asphalt mixture is able to reduce traffic noise, improve pavement performance and reduce maintenance cost (Xiao et al., 2009). This is because it increases the resistance against rutting and thermal cracking, and reduces fatigue damage, stripping and temperature susceptibility (Yildirim, 2007).

2.3.2 Application of Natural Rubber

Chan et al., (2013) stated that NR, also known as cis-1,4-poly(isoprene) has chemical structure as illustrated in Figure 2.1 and is an elastomer that is derived from a milky colloidal suspension from the plants, called NR latex. The typical composition of NR Latex and dry NR are tabulated in Table 2.1. Naturally, the NR is a soft and sticky solid with low tensile strength and low elasticity due to the weak van der Waals force of its intermolecular attraction and occasional crosslinking.

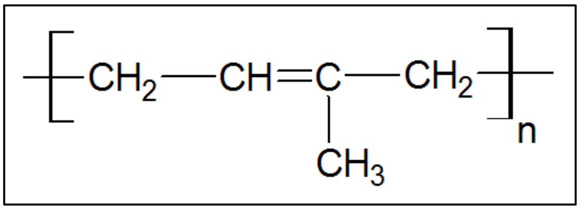

Figure 2.1: Chemical Structure of cis-1,4-poly(isoprene).
(source: http://polymerdatabase.com/Elastomers/Isoprene.html)

According to Azahar et al., (2016), processing of NR has slightly expanded its application on other raw rubber products. Rubber manufacturer uses huge amount of NR to produce rubber end products with high qualities. Through the vulcanization process, it converts the rubber from plastic temperature sensitive materials to technologically-useful elastic materials with the formation of a cross-linked molecular network. For example, gloves, balloons, tubes, and poly(styrene-butadiene-styrene) are the products of NR latex.

Table 2.1: Component and Composition of dry NR and NR Latex (Chan et al., 2013)

	Component	Composition (%)
NR Latex	Total solid content	36
	Dry rubber content	33
	Resinous substances	1 - 25
	Proteinaceous substances	1 - 1.5
	Inorganic salts (mainly K, P and Mg)	0.5
	Ash	< 1
	Sugars	1
	Water	60
Dry NR	Rubber content	93 - 95
	Resinous substances	2
	Proteinaceous substances	2 - 3
	Inorganic salt	< 0.2
	Sugars	< 0.2
	Cu and Mg	2 - 3 ppm
	Water	~ 0.5

In addition, Vo and Plank, (2018) presented that NR latex also acts as film forming additive in cementitious mortar. The latex polymers provide cohesion in the fresh mortar and adhesion on various substrate. Furthermore, it increase the flexural strength of the hardened mortar.

2.4 Anti-Stripping Agent

Stripping of asphalt mixture is the detachment of aggregates and bitumen typically accompanied by the failure in bitumen structure (Haghshenas et al., 2015). These distresses can result in rutting, cracking, shoving, and ravelling of asphalt pavement layer. Therefore, anti-stripping agent is required to incorporate into the asphalt mixture to improve the stripping resistance of the asphalt pavement. Anti-stripping agents are mainly categorized into two types, which are liquid anti-stripping and powder anti-stripping.

Based on Zhu et al., (2018), discovered that adding anti-stripping agent to asphalt mixture could enhance the stripping resistance of asphalt pavement. For example, Zycosoil added into the asphalt mixture increases the surface free energy of adhesion between asphalt binder and aggregates in dry/wet condition. Furthermore, (Park et al., 2017) found that aliphatic amine type-developed anti-stripping agent could improve the stripping and rutting resistance of the asphalt mixture.

Nazirizad et al., (2015) proposed to apply anti-stripping agent to increase the bonding between aggregates and bitumen which improved the wetting resistance and decreased bitumen surface tension.

2.4.1 Liquid Anti-stripping Agents

Curtis, (1990) stated that liquid anti-stripping agents are the additive in the form of liquid cationic surface-active agents, principally amines. There are two major types of surfactants used as liquid anti-stripping which are fatty diamine and fatty amido-diamine. From the study, it is also found that these materials have high thermal stability and the additives of amines effectively promote the good adhesion of bituminous materials.

From (Mirzababaei, 2016) Zycotherm is a silane-based technology which improved the resistance against susceptibility moisture damage. Zycotherm is also known as organosilane additive to the bitumen binder. It creates a molecular level hydrophobic zone which is water repellent. The bonding of bitumen is very renitent against moisture conditions between inorganic parts of hydrogen bond with the hydroxylated agent on the surface of the stone. The organic part is condensed in process of hydrolysis with presence of water. When temperature increases, hydrogen bond collapses, results in the production of H_2O and a covalently bonded metallosiloxan. Therefore, cross-linked siloxane (Si-O-Si) film structure is needed over the surface.

From Vantage Commerce, (2016), Zycotherm allows extended time and temperature of moisture condition parameters, shows excellent retention of wet strength due to the chemical bonding. Zycotherm modified bitumen achieves complete coating faster due to improved wetting and help to saturate the finest pore and cervices of aggregates surface. It also reduces stripping potential and oxidation effects at the aggregate-bitumen interface due to elimination of air interface at the aggregates surface. The pavement fatigue resistance also increases due to the chemical bonding and complete mechanical impregnation of bitumen into the finest pores of aggregates surface.

According to Ameri et al., (2018) Evonik is an acid-based polyamine fatty material in liquid form and its properties was presented in Table 2.2. It acts as asphalt binder additive which is applicable to different types of asphalt cements, cutback bitumen and cationic asphalt emulsion with all kind of aggregates. Evonik consists of inorganic and organic parts and establishes covalent bonding to bitumen and aggregates. Owing to the presence of heat, the hydrogen bonds on the surface of aggregates break, leading to production of H_2O molecules. The inorganic part of anti-stripping agents establishes Si–O–Si covalent links in the presence of H_2O molecules. This mechanism creates a hydrophobic layer which prevents the penetration of moisture in the aggregate-bitumen interface.

Table 2.2: Properties of Evonik (Ameri et al., 2018)

Property	Specification
Physical State	Clear, Liquid
Viscosity	Medium viscous
Acid Value	Approx. 35
Amine Value	Approx. 150
Water Content (%)	Max. 2

Wu et al., (2017) mentioned that Evotherm had evolved from water-based package to less-water Evotherm Dispersed Asphalt Technology (DAT), and to free water third generation. When using the first version of water-based Evotherm, thin film of water is formed between asphalt-coated aggregates which acts as lubricant to improve the mix workability. Therefore, Evotherm improves the coating and workability of the asphalt mixture and acts as an adhesion promoter emulsification agent.

2.4.2 Powder Anti-stripping Agent

Lime is the first generation of anti-stripping agent representative and is still used in many countries (Chuanfeng et al., 2013). Lime efficiently improves the adhesion effect and water resistance of the mixtures. When lime is implemented in asphalt mixture, it covered the contact surface evenly and enhanced through surface modification, which forms many porous rough structures on mineral aggregates contact surface.

Kim et al., (2012) recommended that the additive of fly ash as anti-stripping agent has driven significant attention to the asphalt materials, because fly ash is more economical and convenient to access than other materials. Application in asphalt mixture can potentially benefits the environment and reduces the amount of disposed materials. Additive of fly ash can improve the Hot Mix Asphalt (HMA) performances. The addition of 3-6 % fly ash can effectively improves the moisture damage resistance of the asphalt mixtures. Fly ash also works as a stiffening and void filling agent for asphalt mixture.

2.5 Pavement Distress

2.5.1 Pothole

Pothole is the small or bowl-shaped pavement surface depression that penetrates through the asphalt mixture and base course. Ouma and Hahn, (2017) stated that potholes are classified as surface-elevation related defects. Potholes were caused by the loss of road layer aggregates. Formation of potholes which are normally caused by minor crack or pavement distress, eventually leads to substantial structure damage of road.

Obaidi et al., (2017) suggested that asphalt mixture is used to resist the vehicle load and provide skid resistance for the road users. Due to the extreme weather conditions, the coated bitumen started to degrade chemically. This causes the penetration of water into the void between the structural which causes the degradation of structural loading capacity and adhesion properties of the binder. Frequent loading of vehicles over the aged pavement caused cracking propagation, and aggregates loss, resulting in the pothole formation.

According to Koch and Brilakis, (2011) the pothole severity can be evaluated by using image segmentation, shape extraction and texture extraction. This is less time consuming and the results obtained has a higher accuracy. Kwon et al., (2018) proposed that spray injection is one of the methods for pothole repairing. The operation consists of cleaning the damaged area with compressed air to remove the loose materials and debris. Tack coat of hot asphalt emulsion is applied, the combined aggregate and emulsion are then sprayed into the pothole with forced air. Spray injection method is the least expensive method and provids a better patch service life compared to other patching method.

2.5.2 Ravelling

Ravelling is referred as the process of losing aggregate from the surface pavement (Opara et al., 2016). Ravelling is caused by concentrated mechanical stress, especially from the heavy traffic and the use of chains or studded tires.

Besides, Massahi et al., (2017) also noticed that ravelling is one of the serious pavement distress that leads to the safety issues and frequent road maintenance. The inadequate compaction, pavement placement in wet condition, pavement mix design and binder aging are also the major causes of ravelling distress. Ravelling distress can be determined by using optical measurement and image sensing techniques.

Achener Ravelling Tester, Darmstadt Scuffing Device, Rotating Surface Abrasion Tester and Trinoroute are devices that were developed to evaluate the severity of the road pavement (De Visscher and Vanelstraete, 2017). These devices were used to determine the ravelling resistance and capability of the mixtures of pavement to the shear force induced by traffic.

The pavement distress on ravelling can be repaired by removing the defective area and patch with a higher resilient modulus asphalt mixture at the defective area. Whereas, the large ravelled area which caused the defective of HMA structure can be repaired by removing the damaged pavement and overlay.

2.5.3 Fatigue Cracking

Fatigue cracking is one of the pavement distresses. It is caused by the fatigue failure of the pavement surface due to repeated heavy traffic loading. Gu et al., (2018) identified that the alligator cracking are formed due to adjacent fatigue cracking. The further deterioration of fatigue cracking forms pothole which degrades the pavement serviceability and safety.

In addition, Rys et al., (2017) stated that the high modulus asphaltic concrete is able to increase the resistance towards rutting and fatigue cracking especially on low temperature cracking. Fatigue cracking is mostly caused by the climatic conditions, pavement age, chemical compositions and properties of asphalt binder. The lower penetration grade of bitumen increases the risk of thermal cracking. The use of modified bitumen during pavement mix design can reduce the cost and risk of thermal cracking.

Dhakal et al., (2016) suggested that fatigue cracking of HMA pavement can be treated by using the techniques of crack sealing and overlay, chip seal interlay, full-depth reclamation and cold-in place recycling.

2.5.4 Moisture Damage

Sun et al., (2016) stated that moisture damage is one of the major distresses of asphalt pavement which limits its service life. The penetration of water into the asphalt pavement influences the bonding condition of adhesion and cohesion of the asphalt which leads to the asphalt mixture to lose its strength. According to the study, moisture damage can prevent water from entering the asphalt pavement by improving the adhesion strength of asphalt aggregate-system (Sun et al., 2016).

Bozorgzad et al., (2018) quoted that the moisture damage is the continuous loss of pavement performance due to the loss of adhesion at the aggregates. The moisture damage which are compromised at two stages: a.) Moisture Diffusion Process, b.) Mixture Mechanical Response. In the first stage, it depends on the moisture diffusion type liquid that diffused into the interface between the aggregate and voids. The second stage depends on the change in mixture mechanical properties which leads to reduction of asphalt mixture load-bearing capacities.

Bala et al., (2018) stated that researches on polymer modification asphalt were conducted to enhance the resistance against moisture damage. Besides, it proved that application of various types of polymers enhance the life of asphalt pavements. The polymer increases the viscosity of the binder and thickens the asphalt film coated to aggregates (Fu et al., 2017). Hence, the adhesion between aggregates and bitumen in the mixture is enhanced and the resistance against the moisture damage is increased.

Park et al., (2017) proposed that the potential moisture damage can be controlled or reduced by material selection, mixture design, increasing high asphalt film thickness, use of additives, and drainage system applied. The most common method applied to overcome the moisture damage is introduce additives or modifiers into asphalt binder or the aggregate. This is because the anti-stripping additives is able to increase the bonding strength between the bitumen and aggregate which improved the moisture resistance and decreased bitumen surface tension (Nazirizad et al., 2015).

2.6 Effects of Rubber on the Performance of Asphalt Binder and Mix

2.6.1 Effect of Rubber on Modified Asphalt Binder

Polymer asphalt binder poses greater resistance to rutting, thermal cracking and permanent deformation to the asphalt mixture (Liu et al., 2018) compare to unmodified asphalt binder. Styrene-butadiene styrene (SBS) is one of the common modifiers used in production of modified asphalt. SBS is a kind of block copolymer that improved the elasticity of the original asphalt. A strong bonding strength between asphalt and aggregates is developed owing to network structure created by SBS. This contributes to retard in low temperature thermal cracking, enhancing resistance against high temperature deformation.

According to Al-Adham and Al-Abdul Wahhab, (2018), crumb rubber modified asphalt binder can improve the performance of asphalt binder. When the crumb rubber content increases from 5% to 10%, the viscosity, elastic recovery, softening point and complex modulus also increase. On the others hand, the high content of crumb rubber in the modified asphalt binder reduces the penetration, ductility and phase angle of the binder properties.

Besides, Zani et al., (2017) stated that the compatibility and storage stability of modified binders were influenced by the chemical nature of neat bitumen and the characteristic and content of polymer. These modified binders produced from the bitumen with a higher content exhibit better compatibility and greater storage stability, while an increase in asphaltenes could cause adverse effect. This study also discussed about polymer with better dispersion and higher fineness which can increase the binder properties and stability during storage such as viscosity and elastic recovery (Zani et al., 2017).

Tai Nguyen and Nhan Tran, (2018) mentioned that crumb rubber was added into bitumen to improve the engineering properties of the binder. Specifically, at high temperature, light non-polar fractions are absorbed into the polymer networks. As a result, the final bitumen becomes harder and swelling crumb rubber particles soften. If the binder mixing time is too long at extreme high temperature, the swelling will stop and then be replaced through polymerization.

2.6.2 Effect on Rubber on Modified Asphalt Mix

According to Razmi and Mirsayar, (2018) the rubber modified asphalt mix tends to improve the performance of asphalt mixture and asphalt binder. The rubber modified asphalt mix is able to increase the rutting resistance, reduces the thermal sensitivity and thermal cracking resistance. However, the mixture modified by crumb rubber requires higher mixing and compaction temperature than conventional asphalt mixture. Therefore, more energy and work are required to compact the modified asphalt mixture.

Bai et al., (2016) suggested that modification effects of crumb rubber on asphalt mixtures depend on many factors including the mixing method employed, reaction time of rubber with bitumen, rubber properties, the particle size, and concentration of crumb rubber. The production of crumb rubber modified asphalt mixture improves the rutting resistance, resilient modulus, and fatigue cracking resistance of asphalt mixture. This is because the rubber particles absorb most of the aromatic fraction of asphalt mixtures which increase the viscosity of the asphalt. As a result, the modified rubber is able to coat the aggregate with a thicker film and bind the aggregate closely and firmly.

2.7 Effect of anti-stripping in Asphalt Mixture

According to Oliviero Rossi et al., (2017) the chemical affinity between bitumen and aggregates is favoured by the addition of anti-stripping agent. It modifies the interface properties of both aggregate surface and bitumen. These compounds are known as adhesion promoters. The addition of organic compounds to bitumen is able to increase the coating efficiency onto the stone and promote a better bitumen adhesion. Furthermore, the anti-stripping agent is able to be impaired with the intermolecular interaction between residual water and polar aggregate surface. As a result, the contact energy between bituminous polar liquid phase and the solid mineral phase is reduced.

In addition, Pape, (2017) stated that anti-stripping agent, also known as adhesion promoter or coupling agent, can form a strong adhesive bond between organic polymer and inorganic surface. On the other hand, the anti-stripping agents also improve adhesion, involving chemical modification of polymer surface by oxidation and abrasion of the inorganic substrates to increase the bonding area.

Peng et al., (2018) discussed about the adding organic additives into the asphalt mixture is able to enhance the adhesion between the asphalt binder and aggregates due to the ability of organic additive to reduce the surface free energy of asphalt binder. Thus, it decreases the stripping between the aggregate and asphalt binder with the presence of water.

2.8 Asphalt Mixture Performance

2.8.1 Indirect Tensile Strength

Islam et al., (2015) stated that indirect tensile strength (ITS) is used to evaluate the cracking properties of asphalt pavement by determine the tensile strength of the asphalt pavement. The higher the ITS which has a greater resistance towards the cracking properties of asphalt pavement. ITS also can evaluate the fatigue cracking of asphalt pavement at low temperature.

According to Yang et al., (2017) that the tensile strength represents the adhesive and cohesive strength between the binder and aggregate. This stronger adhesive between binder and aggregates will have a greater resistance towards the cracking performance.

2.8.2 Moisture Susceptibility Index

Moisture susceptibility index is used to determine the serviceability of the asphalt mixture due to the present of moisture in the asphalt pavement (Prez and Pasandion, 2017). The index value is to indicate the water sensitivity. The lower value of moisture susceptibility index which indicate the lesser of the strength reduction by water immersion condition or have a better water resistant.

Yang et al., (2017) stated that moisture susceptibility index is related to the pavement distress of pothole and ravelling. This is evaluating the moisture resistance of the bond between aggregate and binder.

2.8.3 Resilient Modulus

Resilient modulus is to determine the modulus elasticity of asphalt pavement and it is determined by the stresses divided by stain. Rua et al., (2018) stated that resilient modulus is an important parameter to analysing the mechanical behaviour of asphalt pavement and evaluating the long-term performance of the asphalt pavement.

Karami et al., (2018) mentioned that resilient modulus is a criterion of asphalt mixture ability to spread the load and control the level of traffic. The traffic creates a tensile strain on the asphalt mixture layers which will caused the permanent deformation of asphalt pavement. The resilient modulus of a pavement is measured by studying the potential elastic properties of asphalt mixtures in the form of stress-strain measurement. They found that the resilient modulus of modified asphalt pavement is greater than unmodified asphalt pavement.

2.8.4 Dynamic Creep Test

According to Khodaii and Mehrara, (2009) stated that dynamic creep test is to determine the potential of asphalt pavement to occurred permanent deformation.