ASSESSMENT OF DILUTED METHANOL AS A FOAMING AGENT IN LATEX MODIFIED ASPHALT MIXTURE

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By

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ABSTRAK

Gabungan susu getah dalam campuran asfalt telah menarik minat pemain industri kerana ia dapat meningkatkan ketahanan turapan jalan raya. Ciri-ciri elastomer dalam susu getah membuatkan bahan pengikat menjadi lebih tegar dan memerlukan tenaga yang lebih tinggi bagi penghasilan campuran asfalt. Ia mengakibatkan lebih banyak gas rumah hijau terhasil yang boleh membahayakan kesihatan manusia dan alam sekitar. Kajian ini dijalankan untuk menilai kebolehgunaan metanol telarut sebagai ejen pembusa dalam campuran asfalt terpinda susu getah yang dihasilkan pada suhu rendah. Dalam kajian ini, dua ketetapan jumlah metanol telarut (1% dan 3%) disuntik bersama 6% susu getah ke dalam bitumen yang dipanaskan pada suhu 135℃. Manakala, campuran terkawal dan campuran asfalt terubahsuai getah dihasilkan pada suhu 160℃. Campuran asfalt disediakan dan dimampatkan pada 4% dan 7% lompang udara bergantung kepada ujian yang ditetapkan. Ujian makmal telah dijalankan untuk mengenalpasti ciri bahan pengikat, ciri perkhidmatan dan prestasi campuran. Putaran kelikatan, kadar pengembangan dan pemulihan kilasan masing-masing telah digunakan bagi mengenalpasti kelikatan bahan pengikat pada suhu berbeza, kebolehbusaan dan pemulihan pengikat setelah dikenakan daya kilasan. Ciri-ciri perkhidmatan dinilai melalui indeks kebolehkerjaan, indeks tenaga mampatan dan kebolehsalutan yang menunjukkan kelancaran dalam proses penghasilan, salutan agregat dan pemadatan campuran. Tambahan lagi, prestasi campuran telah dinilai untuk mengenalpasti toleransi campuran terhadap kerosakan disebabkan kelembapan, ubah bentuk kekal dan daya ricih. Berdasarkan keputusan, bahan pengikat berbusa menunjukkan kelikatan rendah berbanding asfalt terkawal dan gabungan susu getah meningkatkan kebolehupyaan bahan pengikat secara mendadak.

Indeks kebolehbusaan yang baik dapat dicapai dengan penambahan jumlah metanol telarut. Ciri-ciri perkhidmatan dan prestasi campuran adalah sebanding sekiranya bukan lebih baik daripada campuran asfalt yang dihasilkan pada suhu tinggi.

ABSTRACT

Incorporation of latex in asphalt mixture has gain interest from the industry players as it makes road pavement more resilient. The elastomeric properties of latex make the binder stiffer and require more energy during asphalt mixture production. This would cause higher emission of greenhouse gases which harmful to the human health and the environment. This study aims to assess the applicability of diluted methanol as foaming agent in asphalt mixture incorporating latex produced at lower temperature. In this study, two designated amount of diluted methanol (1% and 3%) injected with 6% latex into the bitumen pre-heated at 135℃. While, the control and latex modified asphalt mixtures were prepared at 160℃. The asphalt mixture was prepared and compacted at 4% and 7% air voids depending on the designated test. Laboratory tests were conducted to identify the binder properties, service characteristics and mixture performance. The rotational viscosity, expansion rate and torsional recovery test were used to determine the viscosity of binder at different temperatures, foamability and its recovery after applying a torsional load, respectively. The service characteristics were evaluated through workability index, compaction energy index and coatability index that indicate the ease of mixing process, aggregates coating and compactibility of mixture. Moreover, the mixture performance tests were evaluated to identify the tolerance of mixture towards moisture damage, permanent deformation and shear force. Based on the result, the foamed binder exhibited lower viscosity compared to control asphalt and incorporation of latex has significantly improved the performance of binder. Better foaming index can be achieved by using higher amount of diluted methanol. The serviceability and mixture performance of foamed asphalt mixtures are comparable if not better than those asphalt mixtures prepared at higher temperature.

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LIST OF ABBREVIATIONS

HMA	**H**ot **M**ix **A**sphalt
WMA	**W**arm **M**ixed **A**sphalt
RA	**R**ubberized **A**sphalt
PMA	**P**olymer **M**odified **A**sphalt
PWD	**P**ublic **W**ork **D**epartment
AASHTO	**A**merican **A**ssociation of **S**tate **H**ighway and **T**ransportation **O**fficials
ASTM	**A**merican **S**ociety **f**or **T**esting and **M**aterials
RV	**R**otational **V**iscosity
UTM	**U**niversal **T**esting **M**achine
SBS	**S**tyrene **B**utadiene **S**tyrene
SGC	**S**ervopac **G**yratory **C**ompactor
ITS	**I**ndirect **T**ensile **S**trength
SSD	**S**aturated **S**urface **D**ry
CRM	**C**rumb **R**ubber **M**odified
LVDT	**L**inear **V**ariable **D**ifferential **T**ransducers
OPC	**O**rdinary **P**ortland **C**ement
PAHs	**P**olycyclic **A**romatic **H**ydrocarbon

NOMENCLATURES

AV	Air voids
WI	Workability Index
CEI	Compaction Energy Index
FI	Foam Index
G_{mm}	Theoretical Specific Gravity of Mix
G_{mb}	Bulk Density
SG_{binder}	Theoretical Specific Gravity of Binder
SG_{agg}	Specific Gravity of Aggregates
P_{binder}	Percentage of binder content
τ_{max}	Maximum Shear Stress
ER	Expansion Ratio
HL	Half-Life
F_{max}	Maximum Shear Force
K_{peak}	Shear Stiffness Modulus
∂_{max}	Maximum displacement
Pa·s	Pascal·second

CHAPTER 1

INTRODUCTION

1.1 Background

Hot mix asphalt (HMA) is the most widely used technology for road construction in Malaysia. The term hot mix referred to the high temperature required for the production and compaction of asphalt mixture ranging from 140℃ to 190℃ depending on mix types (Yildirim et al., 2000, Mohd Hasan et al., 2013) . High temperature is required to ensure the acceptable viscosity of the binder for sufficient workability. Several studies concluded that exposing asphalt binder to high temperature would emits more greenhouse gases and smoke that contribute to global warming and endanger human health including plant operators, paving crews and public in the vicinity area. Due to these concern, new technologies are initiated to improvise the properties of the binder especially the viscosity and the adhesion between binder and aggregates at lower temperatures to promote the sustainable development. These new technologies are referred as warm mix asphalt (WMA).

The WMA technologies reported to be significantly reduced the emission of smoke and fume produced at the asphalt plant. Reduction in temperature would help in reducing the fuel consumption in asphalt production and able to haul paving mix in longer distance. In term of performances, WMA is expected to be similar if not better than HMA. WMA products are currently grouped into three categories: foaming addictive, organic addictive and chemical addictive.

Foaming technique is an example of WMA technology which uses a simple concept of injecting a small amount of foaming agent into hot bitumen. As the foaming agent reaches the boiling point it will vaporises and is trapped in numerous tiny bubble and causes the bitumen to foam and expand, hence increase the volume of binder with a large surface area per unit volume. Besides water as a foaming agent, other materials such as ethanol and methanol is a good choice since they have low boiling point.

Recently, several studies have been conducted to assess the effect of WMA additive In the rubber modified binder notably known as rubberized asphalt (RA). It is due to the RA shows excellent performance by improving the bitumen properties such as its elasticity, cohesion, stiffness and adhesion. Hence, the asphalt mixes pose better resilient towards rutting, moisture damage and permanent deformation. However, incorporation of rubber would require higher temperature than the typical HMA to achieve workable viscosity. One of the most well-known rubber material is latex.

This study was conducted to adapt the idea of using diluted methanol as a foaming agent in RA using latex. To understand the overall performance of this newly proposed mix, it is essential to carry out experimental study to identify the binder properties, its serviceability and the mechanical performances.

1.2 Problem Statement

High energy consumption of HMA is a serious concern due to high usage of burning fuel and produce high amount of greenhouse gases that endanger both environment and human health. The WMA is introduced to reduce the energy consumption during mixing and compaction of asphalt mixes. However, lowering the temperature of asphalt production became a concern since it causes incomplete drying of aggregates. The moisture may trapped in aggregates pore would form a thin layer boundary between the aggregates and binder, causing a microscopic separation of aggregates and binder, known as detachment. Detachment would induce more severe pavement distresses such as stripping and rutting. Hence, it is crucial to improve the adhesion and cohesion of binder that can be achieved by adding latex.

Moreover, the road industry is focusing on incorporation of rubber in asphalt mixture. This is because rubber materials improve the binder properties including stiffness and elasticity thus, making the road more durable against the adverse effects of weather and traffic overloading. Incorporating latex in the pavement can be used to tackle some of the pavement problems associated with strength and services. However, the latex modified asphalt mixture required higher production temperature to achieve the desirable viscosity than the HMA. Therefore, the latex modified asphalt should associate with WMA additive to make it workable at low temperature.

Methanol is an amphoteric material that has both acid and alkali characteristics. However, methanol is slightly more acidic than water unlike the other alcohol which show lower acidity than water. Methanol is a proton donor due to high tendency to donate O-H proton to strong bases such as sodium hydride. Interaction between methanol and latex would cause the latex to coagulate. The hydrogen ions from the acids produced neutralises the negative charge of the rubber particle need to be reduced by introducing water and form the diluted methanol. This is because water is also amphoteric material which could accept hydrogen ion if it is introduced to acidic materials. Hence, methanol needs to be diluted to ensure it can serve as a foaming agent in latex modified asphalt to avoid the coagulation of latex. This study is essential to evaluate the applicability of diluted methanol as a foaming agent for the production of latex modified asphalt mixture.

1.3 Objectives

The primary objective of this study is to evaluate the applicability of methanol as a foaming agent in the rubberized WMA. This study is carried out to complete the objectives listed below:

1. To determine the rheological properties of rubberized foamed binder prepared with diluted methanol.
2. To evaluate the effects of diluted methanol as a foaming agent on the recovery and the bonding characteristic between aggregates and binder.
3. To identify the optimum diluted methanol content based on the foamed binder and WMA mixture performances.

1.4 Scope of Work

The scope of work was limited to binder properties tests as well as the mixture's serviceability and mechanical performance. The performance of foamed latex modified asphalt mixtures using diluted methanol were compared to the conventional HMA and latex modified asphalt mixture that were produced at high temperature. The changes on binder properties after foaming process and were investigated using the rotational viscosity tests, torsional recovery and expansion rate test. The boiling test and static immersion test were carried out to assess the coatability of the asphalt binder onto aggregates. The compactability and workability of specimens were assessed during the compaction process using the data from Servopac Gyratory Compactor. In addition, the moisture damage, Leutner Shear test and dynamic creep tests were performed to compare the mechanical properties of WMA and HMA.

1.5 Significant of Study

High quality highway and pavement structures are subsequently required in line with the increases of heavy vehicles and traffic loads. As a commonly used pavement, asphalt pavement needs to be enhanced to meet the traffic loading under various conditions. Typically the modified asphalt is usually used to promote better adhesions and cohesions of the mixtures to satisfy the requirement of heavy-duty pavements. However, the modified asphalt pavement results in the increases of mixing and compaction temperatures of asphalt mixtures, which has caused the higher emission of greenhouse gases and fumes that endanger both environment and human health. As more effort given towards sustainable development, researchers are committed to come out with environmental friendly materials and technologies without scarifying the durability of the road. In this study, a new approach using combination of WMA technology and rubberized asphalt has been adopted to reduce the temperature and improve the pavement performances.

In addition, the government has keen interest of using latex as an additive in pavement. This is to widely promote the uses of rubber in industrial product so that the demand for natural rubber would be sustained. Moreover, incorporation of latex in asphalt would have significant benefits in pavement industry since rubberized asphalt was proven to be more resilient compared to HMA, hence reduces the maintenance cost.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In recent years, the WMA technology has gained interest among researcher and road builders worldwide due to its ability to lower the energy consumption and carbon emission of gasses and fumes. The WMA asphalt technology able to significantly reduce the temperature for asphalt mixing and compaction by either lowering the viscosity at lower temperature or enhance the adhesion between binder and aggregates. An example of WMA technology is the asphalt foaming technique. Hot asphalt binder is introduced to low heat latent liquid such as water, as the liquid reaches its boiling point is will vaporised then, trapped as foam and expand. The expansion of the binder would significantly reduce the viscosity at lower temperature.

At the same time, modified binder by using rubber also gained a wide interest in asphalt industry. The mixing of rubber such as latex with conventional asphalt binders results in an improvement in the resistance to rutting, fatigue cracking and thermal cracking. Many researchers have found that utilizing latex in pavement construction is effective and economical.

This chapter established the understanding of the application of WMA and rubber modified asphalt as well as their performance. The combination of these additives would improve the pavement properties in term of service characteristic and mechanical performances.

2.2 Warm Mix Asphalt (WMA)

WMA refer to technology that able to significantly lower the mixing and compaction temperature of conventional asphalt mixture either by lowering the viscosity of asphalt binder or promote bonding between aggregates and binder at low temperature (Lee et al., 2009). The WMA permit the reduction of production temperature by 30℃ - 50℃ in comparison to HMA which typically produced at 140℃-190℃ (Yildirim et al., 2000, Mohd Hasan et al., 2017a).

2.2.1 Type Of WMA Additive

WMA additive that available in the market can be classified into 3 types, organic addictive technology, chemical based technology and binder foaming technique (Xu et al., 2017). Organic additive can improve the performances of asphalt binder by reducing the viscosity at low temperature, which is an attribute to the lattice structure formed by wax after cool down. Organic additives usually have low melting point. The most common organic additives are Sasobit and Asphaltan-B (Rodríguez-Alloza et al., 2014).

Chemical additives consist of complicated combinations including surfactants, emulsification agents, aggregate coating promoters and anti-stripping agents. These chemical surfactants would improve the adhesion between binder and aggregates and cohesion between asphalt mix particle at low temperature without changing its flow properties. The third category is the foamed technique which uses a simple concept of introducing foaming agents such as water into pre-heated asphalt, as the foaming agent reached its boiling point, it would vaporised and trapped as foam. The binder would expand, thus the binder viscosity would be reduced. Foamed technique can be done in two methods, either injection of water trough nozzle or by zeolite, a water bearing capsule. Several approaches can be done in WMA but the goal is always to produce asphalt mixture and construction efficiency at lower temperature. Table 2.1 provides some details of the stated WMA technologies.

Table 2.1: Categories of WMA Technologies

Category	**Mechanism**	**Example**	**Source**
Organic Addictive	Lowering the viscosity at lower temperature by introduce lattice structured formed by wax	• Sasobit© • Asphaltan-B©	(Jamshidi et al., 2013)
Chemical Addictive	Improve the adhesion between aggregate and binder, and also contribute to the aggregate coating	• Evotherm© • Rediset© • Cecabase©	(Hurley and Prowell, 2006)
Foamed Bitumen	Introduce water or liquid to the hot bitumen to enable the binder to expand, thus lowering the viscosity of the binder at lower temperature.	• Water injection • Water bearing addictive (Aspha-min© and Adhera©)	(Mohd Hasan et al., 2013)

2.2.2 Advantages of WMA

The immediate benefits of WMA technologies were the reduction of energy consumptions and reduced the emission of greenhouse gases that contribute to global warming. According to Jamshidi et al. (2013), The sustainability of WMA technology is highlighted by the fact that each 10℃ reduction in asphalt mixture production, decreased the fuel oil consumption by 1 litre and CO_2 emission by 1 kg per ton. mixing temperature.

Table 2.2 provides the comparison of energy consumption and mixing temperature reduction WMA technologies compared to HMA at 160℃ mixing temperature.

Table 2.2: Energy Consumption of WMA Technologies

Technology	WAM-Foam*	Aspha-min©**	Sasobit©**	Evotherm©**
Mixing temperature reduction (°C)	43-63	30	18-54	50-75
Reduced energy consumption (%)	30-40	30	20	50-75

Source: *(Mohd Hasan et al., 2017a), ** (Kheradmand et al., 2013)

Moreover, the reduction of gasses emission would improve the working environment for plant operators and paving crew. Almeida-Costa and Benta (2016) reported that several studies indicate that WMA able to reduce between 30% and 50% of aerosol and polycyclic aromatic hydrocarbons (PAHs) emissions.

Low amounts of emissions, fumes and noise allow asphalt plants to be located in non-attainment areas in which there were specific limitations on emissions. This location possibility reduce the transportation distance and avoids traffic congestion (Hurley and Prowell, 2006)

2.3 Foamed Asphalt Mixture

Foamed asphalt mixture was discovered in 1928 when the hot bitumen was patented (Hamed, 2010). Initially, it was a technology used to stabilize the soil then, it was expanded for road base stabilization. Several improvements had been done before it was used in most of countries which adapted the technique. At first, foamed asphalt were mixed with cold aggregates, resulted in poor coating of large aggregates. The method was then improved by using warm or semi-warm aggregates which resulted better aggregate coating (Hailesilassie et al., 2015). Foamed asphalt can be produced either by injecting water approximately 1%-6% to pre-heated bitumen or using water bearing addictive. The foaming technique is used in most of country either in constructing new roads or in recycled asphalt (Mohd Hasan et al., 2013).

2.3.1 Foaming Method

2.3.1.1. Water-based Process

Water-based process used a simple theory which is producing foam by introducing small amount of water into heated binder or by adding moist sand (fine mineral particles) into asphalt mixture (Vaitkus et al., 2016). When a small amount of water was added to the hot asphalt binder, the water vaporized at boiling temperature and trapped in form of bubbles (foam). The binder was then expanded and increased its volume therefore, the viscosity decreased. Reduction in viscosity resulted in better coating of aggregates and workability of asphalt mixture (Mohd Hasan et al., 2017a).

2.3.1.2. Water Bearing Process

Currently, there are two types of water-bearing additives available namely, Aspha-min® and Advera®. The Aspha-min® is hydro thermally crystallizes as a very fine powder, containing about 21% crystalline water by mass. It is added to mix shortly before or at the same time as the binder at a rate of 0.25-0.3% by mass. Upon heating over 100°C, zeolite will break and release water, creating a very fine water spray resulting the asphalt to foam (Lee et al., 2009). Meanwhile Advera® is a synthetic zeolite of hydrated aluminosilicate containing about 18% to 21% of water, recommended dosage between 0.3% to 0.9% by weight of mix to reduce production temperature by 10°C to 20°C. Upon heating above 100°C, water was emitted from the zeolite causing foaming in asphalt mix (Wu and Li, 2017).

2.3.2 Foaming Agents

There are two commonly known techniques to produce foamed WMA, namely foaming admixture and free water system. Foaming admixture technique involved hydrophilic materials such as synthetic zeolite. When the hydrophilic materials interact with hot asphalt binder, they will gradually release water and turned into steam at atmospheric pressure, expanding the binder volume and creating the foaming effect. Meanwhile, water system is the injection of a small amount of foaming agent such as water to produce foamed asphalt binder. The concept behind the free water system is that water would expand by a factor of approximately 1700 when it turns to steam. This expansion of water inside the asphalt will result in a reduction of viscosity, allowing a low temperature for aggregate coating and mixture compaction (Mohd Hasan et al., 2013).

Whereas, water foaming was a very well-developed technique, based on the literature review. Another foaming agent such as ethanol had come to interest of some researchers. Some experimental finding such as volume expansion and viscosity had been reported lately, the greenhouse gas emissions of ethanol foamed WMA were found to be lower than that using water foaming (Mohd Hasan and You, 2015, Mohd Hasan and You, 2016). Ethanol was studied since it has lower boiling point than water. A new interest of using methanol as foaming agent had come across by some researches due to methanol has lower boiling point than water and slightly lower than ethanol. Ethanol and methanol has the boiling point of 78℃ and 65℃ respectively (You et al., 2017).

Moreover, Mohd Hasan et al. (2017b) , hypothetically suggested that there was a small probability that alcohol can react with the acidic groups in an asphalt binder during the foaming process. However, based on the laboratory results by Mohd Hasan et al. (2017b), ethanol alone is unreactive with the asphalt binder.

2.3.3 Mechanism of Foamed Asphalt Binder

In asphalt binder, the foaming process is a dynamic process. Firstly, foaming agent such as water was introduced into hot asphalt binder. The water was then turned into vapours and were trapped in numerous tiny bubbles in the asphalt, causing spontaneous foaming, and greatly increasing the volume of asphalt binder. However, the foam dissipates in a very short time, hence the asphalt materials have to be manufactured within a quick time, while the asphalt binder is still in its foamed state. Foaming processes significantly increase the volume of asphalt binder with a large surface area in the unit volume. When asphalt mixed with aggregate, a strong coating with high shear strength of the mix can be generated. In addition, foamed asphalt is flexible and has a much larger volume. The workability was improved considerably so that the manufacturing of asphalt materials can be operated at a lower temperature within a shorter time. The primary factors that affect the degree of expansion are the asphalt's viscosity and temperature, as well as the content of foaming agent, pressure and flow rate (Mohd Hasan et al., 2017a).

2.4 Asphalt Modification Using Rubber

Polymer is defined as long chemical chains that are made up of many smaller chemicals (monomers) connected together. Polymer is divided to two main basic components which are elastomers and plastomers. Plastomers used to modify bitumen by forming a tough, rigid, three-dimensional network to resist deformation, while elastomers have a high elastic characteristic which could resist permanent deformation by stretching and recovering the original shape (Hamed, 2010).

Over the past decades, Polymer modified binder (PMA) had been represented in many studies. It is reported that PMA able to improve various properties of bitumen including, elasticity, cohesion, stiffness and adhesion. Asphalt pavement would be more stable which was stiffer at high temperature and flexible at lower temperature. In addition, PMA able to improve the fatigue resistance and thermal crack properties of asphalt mixtures (Al-Mansob et al., 2014).

According to Airey (2003), the most commonly used polymer for bitumen modification is the elastomer styrene butadiene styrene (SBS) followed by other polymers such as styrene butadiene rubber, ethylene vinyl acetate and polyethylene. When SBS was blended with bitumen, the elastomeric phase of the SBS copolymer absorbed the oil fractions from the bitumen and swelled up to nine times its initial volume. At suitable SBS concentrations (commonly 5–7% by mass), a continuous polymer network (phase) was formed throughout the PMA, significantly modified the bitumen properties. The SBS increased binder elasticity at high temperatures and improved flexibility at low temperatures. This improvement led to better resistance to asphalt rutting at high temperatures, and decrease cracking at low temperatures.

Natural rubber in asphalt mix improves adhesion properties, the cohesion between aggregates to hold the aggregates together. Natural rubber increases the stiffness of the binder, thereby enhancing the asphalt performance at high temperatures but make it brittle at low temperatures (Al-Mansob et al., 2014).

Yildirim (2007) reported that the natural rubber asphalt modification resulted in better rutting resistance and higher ductility. However, the natural rubber is sensitive to decomposition and oxygen absorption. Natural rubber asphalt mixture has problems of low compatibility due to the high molecular weight. The practical problems in using natural rubber are it needs high temperatures and long digestion times in order to be dispersed in the bitumen.

2.5 WMA Incorporating Rubber

Previous studies showed that application of rubber would benefits asphalt mixture. According to Wang et al. (2012), the advantages of applying crumb rubber modified (CRM) binders into asphalt pavements including reduces the thickness of asphalt overlays but improving pavement life, decreasing traffic noise and maintenance costs, increasing resistance to rutting and cracking. However, the mixing temperatures and compaction temperatures of rubberized asphalt binders were much higher than the typical HMA. In contrast, WMA is a technology to reduce the mixing and compaction temperature of asphalt mix. If the WMA technologies are incorporate well with RA, it would produce a modified asphalt mix with better properties even at low temperature.

However, the influence of crumb rubber and WMA additives mixed with virgin mixtures together has not yet truly understood clearly. The interaction of modified mixtures is not well identified from the standpoint of binder properties and field performance. WMA additives able to reduce the mixing and compaction temperatures but achieved desirable workability of HMA without significantly affecting the engineering properties of the mixtures. In the other hand, the addition of rubberize materials such as crumb rubber increases the demand of asphalt binder and increases the mixing and compacting temperatures, resulted in better resistant towards high temperature deformation and extending the long-term performance of HMA. Because of the complicated relationships of these two materials in an asphalt mixture, detailed information would be needed to obtain the “balance” of these materials (Xiao et al., 2009, Gandhi and Amirkhanian, 2007).

Xiao et al. (2009), conducted experiments to evaluate rheological properties of rubber-WMA mixture and the engineering properties of the mixture. It was reported that the combination of the crumb rubber and WMA additive in asphalt binder is beneficial to improve the rheological properties of both the unaged and aged binders (e.g. increase $G^*\sin\partial$ and reduce $G^*/\sin\partial$ values). The increase in the mixing and compaction temperatures due to the addition of crumb rubber can be offset by adding the warm asphalt additives, which lowers the mixing and compaction temperatures of rubberized mixtures comparable to conventional HMA.

2.6 Pavement Distress

2.6.1 Moisture Damage

Pavement moisture damage deterioration due to HMA is among the major concern of failure in HMA, several methods have been used to investigate the moisture susceptibility of asphalt mixture (Amelian et al., 2014). Moisture damage would causes stripping on the asphalt due to the loss of adhesion or cohesion between binder and aggregates resulting in reduced strength or stiffness of the HMA thus, developed various forms of pavement distresses. Moisture damage happened because of the interference of water to the bonding of aggregates and binder. Low bonding between aggregates and binder would result in striping the ravelling.

WMA of using foamed or chemical surfactant has shown some concern in moisture damage. This is because both techniques involve adding water molecule in the mixture. Low temperature during asphalt mixing would cause the incomplete drying of aggregate due to some water could be trapped in between aggregates and binder matric zones. The water would coat the aggregate then reducing the bond between the two materials. As time goes by, the water would be dissipate out from the system and left an empty space between aggregates and binder, which would results in stripping (Kim et al., 2012). Water can cause stripping in five different mechanisms such as detachment, displacement, spontaneous emulsification, pore pressure, and hydraulic scour (Behiry, 2013).

Xu et al. (2017) found that the water bearing additives such as Aspha-min and Advera would weaken the resistance of WMA towards the moisture damage. In terms of free-water WMA mixtures, a proper additive content and a sufficient temperature are crucial and should be optimized, in order to obtain the nice coating of binders onto aggregates and reduced trapped moisture. Organic additives are generally considered to have slightly detrimental effect on the moisture sensitivity of WMA mixtures. Chemical additives are generally considered to be beneficial because of their adhesion promoters that stronger the aggregates-binder bond.

According to Bala et al. (2018), the application of polymer modified binder in asphalt mix would enhance the resistant against moisture damage. This is because polymer increased the viscosity of the binder and thicken the asphalt film to coat aggregates in a mix. The bond between aggregates and binder would be improved to defend the mix from moisture damage.

2.6.2 Rutting

Rutting distress manifest as longitudinal depression on pavement due to the effects of temperature and repeated traffic loading, which appear as depression at the wheel path and small upheavals to the sides. Rutting depression could trapped water, hydroplaning for passenger cars would become safety concern beside difficult to steer the vehicle (Javilla et al., 2017).

Rutting is considered as one of the major pavement distress especially in WMA. This is because lower production and compaction of asphalt mixture would be a concern to rut. Low production temperature of WMA increases rut susceptibility due to less aging since aging improves rutting resistance. Moreover, WMA technology such as foamed WMA is being questionable in terms of rutting and stripping long terms performances due to several study exhibit that foamed WMA as an equivalent to conventional HMA in terms of short-term rutting behaviour (Bairgi et al., 2018).

Most of the rutting performance test could be categorized into two namely, direct indicator and indirect indicator. Direct indicators could be defined as those determined from tests which simulates the effect of traffic such as the wheel tracking test or dynamic creep test. Indirect rutting indicators are determined from tests which were fundamentally different from repeated loading tests such as the simple punching shear test (Faruk et al., 2015).

2.7 Rheological Properties of Asphalt Binder

Viscosity of asphalt binders is closely related to the flow properties and high temperature performances. The viscosity of asphalt binder could be determined by using the Brookfield Viscometer. The viscometer consists of a series of spindle which was immersed into a fluid vessel and enables scale deflection to be measured for a given rotational speed of the spindle. The Brookfield Viscometer is essentially a quality control instrument whereby data is given in terms of scale deflection, spindle number and speed of rotation (Williams, 1979).

One of the benefits for elastomer modified asphalt is the recovery from deformation. The torsional recovery test was developed by Thompson and Hagman, and is in specifications in California to identify the presence of elastomer especially in latex modified asphalt. The test used a simple concept of applying torsional force to asphalt binder for 180º rotation , then the percentage of recovery was measured (King et al., 1999).

An appropriate parameter for characterising foamed bitumen is one that reflects the ability of the foam to be mixed with mineral aggregate. The expansion ratio is a measure of the viscosity of the foam whilst the rate at which the foam collapses is defined by the decay curve, which is an indication the time available for mixing. The area under the decay curve for a particular foamed bitumen will therefore be the desired characteristic. This area has been defined as the Foam Index (Jenkins et al., 1999).

2.8 Mixture Performance

2.8.1 Moisture Damage Test

One of the methods to identify the moisture damage in asphalt is by Modified Lottman test. The concept of this test is to access the severity of the sample that was damaged by the effect of water to the unconditioned sample that should possess the highest strength of the asphalt mixture. The conditioning sample underwent the freeze and thaw cycle that caused damage to the asphalt sample and the strength of the sample was access by means of tensile stress. The severity of damage was compared in form of ratio to the sample that do not underwent conditioning, which have higher tensile strength (Abuawad et al., 2015).

2.8.2 Leutner Shear Test

The Leutner Shear test was the piece of equipment used to assess bonding between pavement layers. The test, invented in Germany in 1979 by R. Leutner, was performed on 150mm diameter cores either taken from a pavement or produced in the laboratory. The bond of asphalt mixture is very important as if the bond of asphalt interface be inadequate, the strains throughout the pavement will increase (under trafficking) and its life will consequently be reduced (Sangiorgi et al., 2003).

2.8.3 Dynamic Creep Test

Dynamic creep modulus is a simple variation of the Young's elastic modulus denoted as E as the materials is no more elastic, it is exposed to the permanent deformation (Badaruddin, 1995). Dynamic creep test is a popular option to study the permanent deformation of asphalt especially rutting. To stimulate the actual environmental conditions, under the influence of different temperature and repeated loading conditions (e.g., frequency, duration, load cycles, and stress level) on permanent deformation, the test can be evaluated and incorporated under Universal Testing Machine (UTM). Moreover, it is reported that results from the dynamic creep tests are so closely correlated with the results of wheel tracking test (Katman et al., 2015).

2.9 Summary

This chapter summarizes the different types of WMA technologies available, rubber modified asphalt and application of WMA in rubber modified asphalt. From the literature reviews, WMA is a technology that able to reduce the asphalt production and compaction temperature but maintaining the performance of the asphalt. However, due to the low temperature, the WMA technology is susceptible to moisture damage that would induce more severe pavement distress. In contrast, rubber modified asphalt reported to have excellent bonding between aggregates and binder, hence reduce the possibility of asphalt stripping. However, incorporation of latex would improve some binder properties by increasing the viscosity and required more energy to achieve desirable workability.

Therefore, researchers were focusing on the incorporation of both WMA and rubber in asphalt mixture to overcome the disadvantages of both WMA and rubber modified asphalt individually. From the previous results, the complex relationship between WMA and RA had showed impressive results for service characteristic and mixture performance compared to HMA. In short, the idea of producing more resilient pavement at low temperature could be achieve and more combination of WMA and RA need to be investigated.

CHAPTER 3

METHODOLOGY

3.1 Overview

Experimental approach was used for this study. The samples are divided into two categories, prepared as foamed WMA that required production temperature at 135℃ and prepared as HMA which used higher temperature (160℃). The control sample is the typical HMA which used the virgin bitumen as the binder. Comparison of performance was made for the sample prepared with 6% latex at 160℃ and two foamed mixture containing 1% and 3% of diluted methanol with 6% latex at 135℃. The experimental works were divided into three parts. Part one is the testing of asphalt binder to determine the binder properties of control (60/70), 6% latex modified binder and foamed latex modified binder. The second part was to determine the service characteristic of loose asphalt mixture which involved compaction energy index, workability index and coatability. The last part was to access the mixture performance by means of moisture damage, tensile strength, shear strength and permanent deformation rate. Figure 3.1 represent the flowchart of for the research methodology.

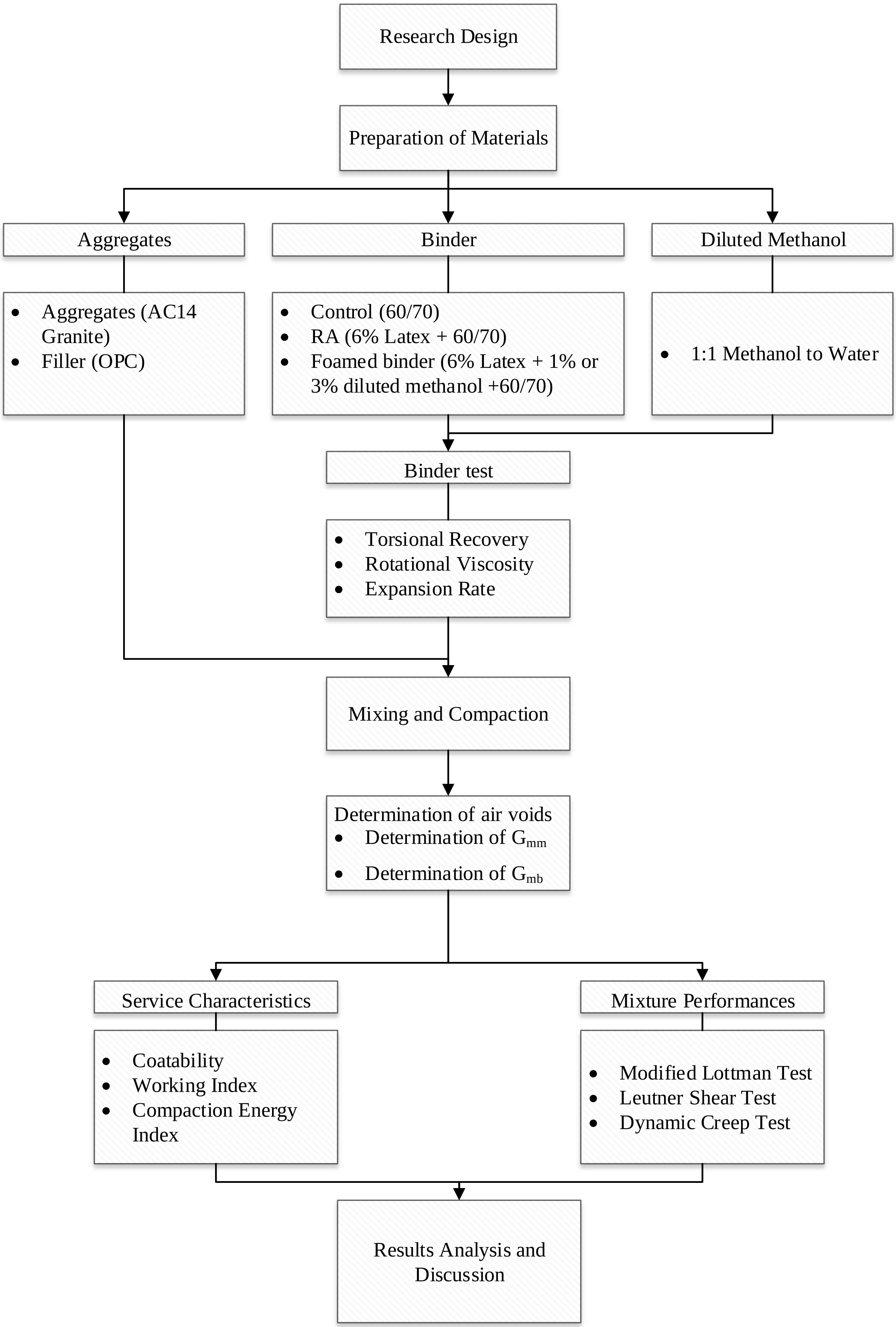

Figure 3.1: Flowchart of the Research Methodology

3.2 Preparation of Materials

3.2.1 Aggregates Preparation

Granite and Ordinary Portland Cement (OPC) were used as the aggregate and mineral filler, respectively in this study. The aggregates were taken from stockpiles, washed and oven dried for 24 hours at 105℃. After sieving process, the aggregates and fillers were batched to produce a specimen weighing approximately 1150g in accordance to Public Works Department of Malaysia's (PWD Malaysia) Standard Specification Road Works (AC14 – JKR/SPJ/2008). The gradation is as shown in Table 3.1. Prior to mixing process, the aggregates were heated at temperature of 135℃ or 160℃ based on the mix type for minimum of 4 hours.

Table 3.1: AC14 Aggregates Gradation

BS Sieve Size (mm)	Percentage Passing by Weight	Median (%)	Mix Design of AC 14 (%)	Cumulative Mass of Aggregate 1150 (g)
20.0	100	100	0	0
14.0	90 - 100	95	5	57.5
10.0	76 - 86	81	14	218.5
5.0	50 - 62	56	25	506.0
3.35	40 - 54	47	9	609.5
1.18	18 - 34	26	21	851.0
0.425	12 - 24	18	8	943.0
0.150	6 - 14	10	8	1035.0
0.075	4 - 8	6	4	1081.0
Filler			4	1127.0
OPC			2	1150.0

3.2.2 Latex Modified Binder Preparation

An amount of bitumen was pre-heated at 160℃ for two hours. 6% of latex by mass composition of asphalt binder was blended with 60/70 binder for 20 minutes to produce the latex modified asphalt binder. The binder mixture was mixed in a vessel and a propeller mixer at the speed of 1000 rpm was used.

3.2.3 Foamed Asphalt Binder Preparation

The foamed rubberized asphalt was prepared in-situ before the mixing process take place. The 60/70 bitumen was heated at 135℃ for two hours before blending. The diluted methanol was prepared by adding methanol into the distilled water with a ratio 1:1 by weight. The diluted methanol was then added onto the latex with the designation as shown in .The diluted methanol and latex mixture were injected into the hot asphalt binders using a syringe at the bottom of the container followed by stirring with a steel rod until the binder is foamed.

Table 3.2: Sample Designation and Composition of Prepared Asphalt Binder Sample

Sample Designation	**Diluted Methanol (%)**	**Latex (%)**	**Production temperature (℃)**	**Compaction temperature (℃)**
Control Sample	0	0	160	150
6% Latex	0	6	160	150
1% d.meth+6%L	1	6	135	125
3% d.meth+6%L	3	6	135	125