ENGINEERING PROPERTIES OF ASPHALT MIXTURE MODIFIED WITH CUP LUMP RUBBER

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SCHOOL OF CIVIL ENGINEERING
UNIVERSITI SAINS MALAYSIA
2020

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by

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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

July 2021

Appendix A8

UNIVERSITI SAINS MALAYSIA

SCHOOL OF CIVIL ENGINEERING
ACADEMIC SESSION 2020/2021

FINAL YEAR PROJECT EAA492/6
DISSERTATION ENDORSEMENT FORM

Title: Engineering Properties of Asphlat Mixture Modified with Cup Lump Rubber

Name of Student: Lee Zhi Zun

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

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Date : 29/07/2021

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Date: 2/8/2021	Date: 3 /8/2021

(Important Note: This form can only be forwarded to examiners for his/her approval after endorsement has been obtained from supervisor)

ACKNOWLEDGEMENT

First and foremost, I would like to express my utmost gratitude to my supervisor, Dr. Zul Fahmi Mohamed Jaafar for his motivation and guidance throughout this study. Without his motivation and guidance, this study will never be achieved. Dr. Zul had given a lot of comments and recommendations on this research. I am grateful towards his continuous monitoring to ensure my work progress is always on the right track.

Next, a sincere thanks to the assistant engineers of the Highway Engineering Laboratory, Universiti Sains Malaysia Engineering Campus, Mr. Mohd Fouzi Ali, Mr. Shamsul Ishak and Mr. Zulhairi Ariffin for their guidance throughout my works. They guided me on how to operate the machines and apparatus in a proper way. Also, I would like to thank to Mr Mohd Fahmi Haikal Bin Mohd Ghazali and Mr Muhammad Haikal Bin Abdul Halim who are a master student and an internship candidate for assisting me to conduct several tests according to the standard procedures. Not forget to mention, a sincere thanks to the School of Civil Engineering, Universiti Sains Malaysia for providing a cosy environment and updated laboratory facilities to work on.

Last but not the least, I greatly appreciate my family members for their loves and continuous supports. Also, thank you very much to my friends who do assist me in my study.

ABSTRAK

Sejak kebelakangan ini, harga getah global yang tidak stabil disebabkan oleh pengeluaran getah yang banyak daripada negara-negara pengeluar getah. Ini disebabkan oleh penggunaan getah sedunia lebih rendah daripada pengeluaran getah dari negara-negara pengeluar getah. Oleh itu, pihak kerajaan dan industri telah menyarankan beberapa pendekatan dengan tujuan meningkat penggunaan getah domestik di Malaysia. Oleh itu, pelaksanaan teknologi asfalt getah dalam pembinaan jalan raya kini menjadi perhatian kerajaan Malaysia. Walau bagaimanapun, jumlah kajian-kajian yang berkaitan dengan prestasi asfalt-asfalt tersebut adalah masih terhad. Oleh yang demikian, kajian ini akan menekankan kepada bagaimana penambahan ketul getah akan mengubah sifat-sifat asfalt konvensional daripada segi ketahanan ubah bentuk, modulus kebingkasan dan modulus rayapan dinamik. Kajian ini bertujuan untuk menentukan kesesuaian asfalt yang diubahsuai dengan ketul getah untuk mengganti asfalt konvensional. Dalam kajian ini, dua jenis sampel telah diuji iaitu aspal konvensional sebagai kawalan dan asfalt ketul getah yang diubahsuai. Pada mulanya, kandungan pengikat optimum (OBC) untuk asfalt-asfalt akan ditentukan iaitu sebanyak 4.57% dan 5.22% untuk asfalt ketul getah dan asfalt konvensional masing-masing. Seterusnya, kandungan tersebut akan digunakan dalam penyediaan sampel yang hendak diuji seterusnya. Ujian-ujian makmal yang akan diuji pada spesimen tersebut adalah Ujian Jejak Roda Hamburg, Ujian Modulus Kebingkasan dan Ujian Rayapan Dinamik. Ujian-ujian tersebut adalah dilakukan dengan tujuan untuk mengetahui bagaimana sampel bereaksi ketika pemuatan diterapkan padanya. Berdasarkan keputusan yang diperoleh, didapati, asfalt ketul getah mencatatkan sebanyak 26.7% dan 48.0% lebih baik berbanding dengan asfalt konvensional dalam Ujian Modulus Kebingkasan dan Ujian Rayapan Dinamik. Hal ini disebabkan oleh asfalt yang merangkumi ketul getah telah meningkatkan keanjalan dan kelikatan spesimen.

Sebaliknya, untuk kes Ujian Jejak Roda Hamburg, kedalaman jalan dari asfalt yang diubahsuai lebih dalam daripada aspal konvensional pada 20,000 lintasan. Walau bagaimanapun, asfalt yang diubahsuai menunjukkan prestasi yang lebih baik pada peringkat awal dalam Ujian Jejak Roda Hamburg. Kepadatan asfalt konvensional berlaku dengan cepat dan kedalaman jalannya mencapai nilai maksimanya pada lebih kurang 2,000 lintasan. Sebaliknya, pemadatan asfalt diubahsuai dilaku dengan perlahan telah menyebabkan kedalaman jalan meningkat secara berterusan sehingga kedalamannya melebihi kedalaman asfalt konvensional.

ABSTRACT

Recently, it is reported that the unstable global rubber price is due to over production from those rubber producing country. This is because the usage of the rubber internationally is less than the production of rubber from those rubber producing countries. Consequently, Government of Malaysia and industries had suggested a few approaches with purpose of increasing the domestic rubber usage within Malaysia. Hence, implementation of rubberized asphalt technology in the road construction currently had become main concern of the government. However, there are still have limited research, which is related to the performance of rubber modified asphalt. Consequently, this study will focus on how the addition of the cup lump will alter the original properties of the Conventional Asphaltic Mixtures in term of rutting resistance, resilient modulus as well as dynamic creep modulus. This study served a purpose to determine the suitability of the Cup Lump Rubber Modified Asphalt (CRMA) to replace the Conventional Asphalt (CA). In this study, two specimens were tested which are CA which acted as a control and CRMA. Initially, the Optimum Binder Content (OBC) for the asphalt was determined which are 4.57% and 5.22% for CRMA and CA respectively. Thus, the specimen that which are tested were prepared based on the OBC. The laboratory tests to be tested on the specimen were Hamburg Wheel Tracking test, Resilient Modulus test, and Dynamic Creep test. These tests were done to determine how the specimen reacted when loads are being applied to the specimen in different manners. Based on the results from the tests, CRMA performed 26.7% and 48.0% better than that of CA in resilient modulus and dynamic creep test. This is because the inclusion cup lump rubber had increased the elasticity and viscosity of the specimen. However, in the case of the Hamburg Wheel Tracking test, the rut depth of the CRMA is greater than that of the CA at 20,000 passes which is not what he had expected. However, the CRMA showed a better rutting performance initially or

early stages. The densification of the CA took placed rapidly, and its rut depth reached to an optimum only after 2,000 passes approximately. On the other hand, densification of the CRMA took placed slowly which resulting its rut depth kept increasing and went beyond the rut depth of the CA after certain number of passes.

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LIST OF SYMBOLS

V_a	Air Voids
G_{mb}	Bulk Specific Gravity/ Bulk Density
M_R	Resilient Modulus
G_{agg}	Specific Gravity of Aggregates
G_{bit}	Specific Gravity of Bitumen
G_{mix}	Specific Gravity of Mix
VMA	Voids in Mineral Aggregates
VFB	Voids filled with bitumen

LIST OF ABBREVIATIONS

AASHTO	**A**merican **A**ssociation of **S**tate **H**ighway and **T**ransportation **O**fficials
AIV	**A**ggregate **I**mpact **V**alue
ASTM	**A**merican **S**ociety **f**or **T**esting and **M**aterials
CRMA	**C**up **L**ump **R**ubber **M**odified **A**sphalt
CA	**C**onventional **A**sphalt
HMA	**H**ot **M**ix **A**sphalt
ITS	**I**ndirect **T**ensile **T**est
JKR	**J**abatan **K**erja **R**aya
LDVT	**L**inear **V**ariable **D**ifferential **T**ransducers
LTOA	**L**ong **T**erm **O**f **A**ging
LAAV	**L**os **A**ngeles **A**brasion **V**alue
MRB	**M**alaysia **R**ubber **B**oard
OBC	**O**ptimum **B**inder **C**ontent
PWD	**P**ublic **W**ork **D**epartment
STOA	**S**hort **T**erm **O**f **A**ging
SSD	**S**urface **S**aturated **D**ry
UTM	**U**niversal **T**esting **M**achine

CHAPTER 1

INTRODUCTION

1.1 Introduction

It is reported that the traffic volume on the highway keep increasing every year, thus causing higher heavy load repetitions on pavement structures. Those high trafficked areas include main traffic carriageway, toll area, car park, and intersections. A significantly higher traffic volume accelerated pavement condition deterioration, both pavement surfaces and pavement structure after a certain duration. Repetitive traffic congestions over a long period imply a great load on pavement which initiates cracking or rutting distresses (Bahruddin et al., 2020). Rutting is caused by accumulation of permanent deformation on every layer of the pavement structure (Shaffie et al., 2017). This distress type indicates road deterioration at the worst stage. Therefore, researcher worldwide initiate studies on asphalt mixtures with different additives to enhance the performance of the mixtures. One of those initiatives is the addition of the processes natural rubber known as cup lump into the bitumen and eventually mixed with the predetermined aggregates and filler, according to the gradation as in the specification. This type of modified binder is prepared and delivered upon request from local suppliers in Klang, Selangor and in Pasir Gudang, Johor.

Malaysia is a blessed country where it consists of many valuable natural resources such as rubber plantation. As of today, Malaysia is a leading producer country of rubber only after Thailand and Indonesia (Azahar et al., 2016). Consequently, it reflects the emergence of the rubber industries in Malaysia such as glove industry, tire industry and others. Malaysia is a major producer and exporters of surgical latex gloves. Malaysian manufacturers currently supply 60% of the natural rubber demand worldwide. In 2016, Malaysia accumulated annual revenue with amount of more than 20 billion Ringgit

Malaysia by exporting natural rubber (MATRADE, 2016). However, unstable global economic had greatly affect the manufacturing plant which requires rubber such as automobile industry. Hence, the demand of rubber in those industries had declined. This incident had decreased the worldwide rubber consumption rate. Consequently, an excess rubber production in worldwide and unstable global economic had caused the fluctuation of global rubber price (Surendan and Ng, 2020). Thus, country which is rich in rubber had to look for a way to stabilise the global rubber price. Hence, to boost the use of natural rubber in a large scale, rubberised asphalt technology in the road construction currently become main concern of the leaders especially natural rubber producing nation such Malaysia, Thailand, and Indonesia (Prastanto et al., 2019). This arrangement also aims to increase the domestic rubber consumption in their country yet to strengthen and stabilized the international rubber price. The inclusion of natural rubber in asphalt for road pavement in Malaysia had increased domestic usage to stabilize rubber price and reduced the impact on around 300,000 smallholders (Kamal et al., 2020). The use of rubber in asphaltic mixture became an interest to the asphalt industry due to its potential to provide better asphalt mixture that is less prone to permanent deformation, skidding, and fatigued related distresses (Othman et al., 2018).

Consequently, the uses and research on the Cup Lump Rubber Modified Asphalt (CRMA) in Malaysia gradually escalated since 2017. The physical properties of the rubber includes high elastic due to high stretch ratio and high resilience (Al-Sabaeei et al., 2019). This is because the molecular chains of polyisoprene, formed a linear chains under loading, and it will returns to its original state when the load is removed (Al-Sabaeei et al., 2019). Thus, it is stated that the elastic property of rubber potentially poses excellent tear strength, high stability, and also great fatigue resistance which had increased the durability of road pavement (Azahar, et al., 2019). Consequently, modifying the asphalt with cup lump could increase the quality of the asphaltic mixtures. Hence, a lot of research had been carried out on the performance of the CRMA to prove that cup lump rubber is a good modifier on improving the performance and quality of the modified asphalt (Azahar et al., 2019).

According to an article (Malaysia's new rubberised road technique a world-first, 2017), Malaysia is the first country to apply such rubberised technology asphalt into the federal road networks. An intermediate 10 kilometres of road from the Federal Road FT001 which is a 40 km highway spanning from Kampung Desa Bertemu Jodoh to Taman Kwong Sai was constructed by CRMA. This road had initiated implementation of this modified asphalt mixtures including Route 4, Jalan Kupang, Gerik, Baling, Kedah (Razali et al., 2019) and Jalan Kuala Lumpur – Kuantan, Temerloh district, Pahang (Othman et al., 2018).

1.2 Problem Statement

In general, for the past five years, the price of the natural rubber was decreased tremendously due to an exceeded rubber production. In 2016, the price reached the lowest value at RM5,320 per ton since 2008 (Index Mundi, 2021). As a consequent, low natural rubber price causes less interest for a more natural rubber production due to the limited profit. Thus, the Malaysian Rubber Board (MRB) has appointed manufacturers to come out an idea on the implementation of rubberised asphalt technology to increase the domestic use of the natural rubber. One of the approaches is by incorporating the processed natural rubber into asphalt mix. According to the MRB, the CRMA road requires an estimated of 4.2 tonnes of the rubber per kilometre of modified asphalt road. The increased application of the rubberised asphalt can boost the domestic demand and stabilised the global rubber price (Malaysia's new rubberised road technique a world-first, 2017). In 2019, the government has allocated around RM 100 million for the maintenance works and the construction of new roads by using the CRMA in ports and industrial areas. This statement is stated by the Former Primary Industries Minister of Malaysia (Minister: 100m allocation for rubberised roads in ports industrial areas, 2019). Other than that, the quality of the CA can be improved in terms of its strength and durability. Therefore, the CRMA was incorporated to improve the performance of the asphalt mixture.

This study is carried out due to limited number of research on the performance of CRMA in term of rutting resistance, resilient modulus, and dynamic creep. Thus, this research is carried out to study the properties of the Cup Lump Rubber Modified Asphaltic Mixture in term of rutting resistance, resilient modulus, and dynamic creep yet to compare the results with the CA mixture. This is to determine whether CRMA perform better as compared to the Conventional Asphalt Mixture.

1.3 Research Objectives

The following objectives were set for this research:

1. To evaluate the performance and the quality of the CRMA in terms of resilient modulus and dynamic creep modulus.

2. To evaluate the performance and the quality of the CRMA in terms of rutting resistance.

3. To compare laboratory test results of the CRMA with control sample.

1.4 Scope of Study

This study covers the modification of the asphaltic mixtures by using the CRMA. The asphalt mixtures were prepared according to the Public Work Department (PWD) specifications or JKR standard specification for road works (JKR-SPJ-2008-S4). The ACWC14 gradation for dense asphalt pavement is selected for sample preparation. The physical properties of the asphaltic mixture are then to be tested with several laboratory tests. These tests included the Hamburg Wheel Tracking Test, Indirect Tensile Strength (ITS) test, Resilient Modulus (M_R) test, Dynamic Creep test, and Marshall Mix Design. The Conventional Asphaltic Mixtures are prepared using the 60 / 70 penetration grade binder and used as a control sample. The results are analysed and compared in order to determine whether cup lump can improves the physical properties of the asphaltic mixtures in term of resilient modulus, dynamic creep, and rutting resistance. All test results are referred to the JKR standard specification for road works (JKR-SPJ-2008-S4) for decision making criteria.

1.5 Significance of Study

The amount of the vehicles on the highway pavement keeps increasing tremendously causing an increase in the traffic volume. A significantly higher traffic volume accelerated the deterioration of pavement condition for both pavement surfaces and pavement structure after a certain duration. Consequently, high quality asphaltic pavement are required to cater this situation in order to prolong the life span of the pavement. Several studies had been done and CRMA is proposed due to its potential in improving the performances and durability of the asphaltic pavement. Thus, the rubberized asphaltic technology had become a game changer in the pavement industry. Several researches had been done proving that the incorporation of cup lump in asphalt modification can improve the quality of the asphalt pavement road effectively. With greater rutting resistance, suitable resilience modulus value, and dynamic creep modulus value, the pavement will last longer under repetitive traffic loads and reduce the needs of frequent maintenance and rehabilitation treatments.

For the past five years, the price of the natural rubber decreased tremendously due to an exceeded rubber production and unstable global economics. In 2016, the price reached the lowest value. This incident had given a huge impact on the rubber industries in Malaysia. Thus, several suggestions had been proposed by the government ministries or bodies and industries in order to stabilise the global rubber price by increasing domestic usage of rubber and incorporating cup lump rubber into the pavement industry is one of the solutions. According to the MRB, the CRMA road requires an estimated of 4.2 tonnes of the rubber per kilometre of modified asphalt road. Thus, the increased application of the rubberised asphalt can boost the domestic demand and stabilised the global rubber price.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Currently, the production of the rubber in Malaysia is greater than domestic usage and export. Increase rubber usage domestically contributes towards increase demand of natural rubber usage and boost the income for workers involved in natural rubber production, domestically. The use of natural rubber as an asphalt modifier can relieve the economic impact on the rubber industry yet improving road infrastructure (Daniel et al., 2019). Previous study showed that natural rubber potentially imparted high tear strength, high stability, and fatigue resistance which increased the durability of pavement (Azahar et al., 2019). This is because the rubber particles will react with aggregate particles. The reacted particles became tacky and improved the adhesion (Azahar, et al., 2019). Currently, there are other modifications carried out to improve the properties of asphalt pavement such as materials from agriculture as an aggregate replacement becomes a trend in the construction industry. The goal is to minimize the production of waste, environmental friendly yet improving pavement performance and quality (Yaacob et al., 2018). However, cup lump is chosen for this research due to its availability in Malaysia.

2.2 Brief Description on the Cup Lump

Natural rubber is a plant-produced polymer, which is a chemical compound with chains of molecules. Natural rubber are harvested from latex, which is a milky liquid, which is present in latex vessels of a rubber tree or Hevea Brasiliense as its scientific name (Suaryana & Sofyan, 2019). Liquid latex make up only around six percent of Malaysia's rubber production while the rest is known as "cup lumps", which is the latex that is coagulated in the collection cups. Therefore, the term “cup lump” here refers to the coagulated material found in the collection cup, which was dried, grinded, and mix with the bitumen and aggregates to produce the CRMA stated by Malaysia Rubber Board (MRB).

Cup lump is the coagulated rubber, which can be found in the rubber collection cups in the rubber plantation or rubber estate. Cup lump are the coagulant from the latex, which attached to the wall of the collection cups after the latex are collected. The cup lump can be harvested at the next visit of the day where the latex is collected by the rubber tappers. According to Ansari et al (2021), cup lump natural rubber can be obtained by adding formic acid into the collection cup to fasten the coagulation process of latex.

Figure 2.1 Cup Lump rubber harvested from the collection cup

Rubber is well known for its elastic property, which can induce high strength, and it has the ability to return to its own original state after the induced strength are removed (Al-Sabaeei et al., 2019). Hence, these characteristics of the rubber or cup lump might be able to enhance the properties of the asphaltic mixture when they are acting as a modifier. According to Ansari et al. (2021), natural rubber have a few beneficial properties namely; high elasticity, high tensile strength, flexible, crack resist, and generate low heat. Natural rubber is built up from chains of poly-cis-1,4 isoprene with a chemical formula of C_5H_8. The chemical structural of the natural rubber is shown in Figure 2.2 below:

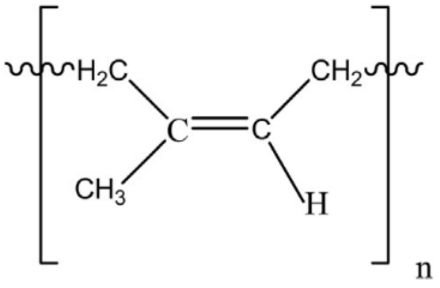

Figure 2.2 Chemical structure of cis-1, 4-polyisoprene in natural rubber (Ansari et al., 2021)

According to Ansari et al. (2021), the repeated unit of the isoprene which are double bonded easily crosslinked or vulcanized which contributed to the three-dimensional structure of the rubber. This had given the rubber a stable elastic property. Natural rubber is elastic due to its high stretch ratio and resilience characteristic. When the load is applied on the chain of polyisoprene, it acts somehow a linear chain. When the applied load is removed, it wrinkles back to its original state. In asphalt pavement preparation, the use of cup lump is more desirable than latex due to the short mixing time and lower mixing temperature (Bahruddin et al., 2020).

Abdulrahman et al. (2020) reviewed the potentials of natural rubber in bitumen modification. According to the researcher, polymer improved the rheological properties of the bitumen by dissolving and distribution its long chain molecules to create a network of inter-connecting polymers. These inter-connecting polymers strengthened the properties of the bitumen.

Rubber is a polymetric material where it is elastic in properties. It can recovers to its own state after the applied load is removed. It is noted that the empirical formula of natural rubber is (C_5H_8). It is imperative to note that the presence of C=C double bond leads the rubber to have such properties.

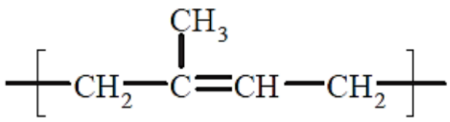

Figure 2.3 Chemical structure of natural rubber (Ansari et al., 2021)

It was also found that the addition of natural rubber decreased the penetration value and increased the softening point of bitumen. Other study found that natural rubber exhibited a shear thinning behaviour which increase its shear rate and reduces the viscosity (Abdulrahman et al., 2020). Links and bonds are formed when rubber particles in dispersion make contact, but under the influence of shearing stress the links are stretched, distorted, and ruptured leading to the reduction in viscosity (Abdulrahman et al., 2020).

Azahar et al. (2019) tested four different samples which are the CA, 5%, 10%, and 15% of CRMA. The physical properties of the modified asphalt with different percentage of modifier were assessed in terms of the penetration value, softening point, and penetration index. The result showed that the asphalt with 5% of modifier had the most promising results with the lowest penetration value and the highest softening point. This is because the addition of the cup lump hardened the asphaltic mixture, enhancing stiffness yet increasing the softening point of the mixture. If the modifier raised to 10% or greater, the penetration value increased, and the softening point decreased. This is due to the properties of the natural rubber that without modification or vulcanization produces rubber that is not elastic, soft and sticky at ambient temperature, and has low tensile strength due to the weak van der Waals forces of intermolecular attraction and crosslinking.

2.3 Standard Laboratory Scale Test for Asphalt Assessment

The following subchapters describe the standard laboratory scale test conducted to assess the quality of asphalt mixtures. The information regarding to the scale test are reviewed and concluded from different sources.

2.3.1 Rutting Resistance

Rutting or permanent deformation is one of the distresses observed in the pavements, mostly due to increasing traffic volume with heavier loads. The accumulation of unrecoverable strain which results from the applied heavy wheel loads, causing a reduction in the service life of the pavements (Huang & Sun, 2020).

According to Siswanto (2016), rutting is the longitudinal depression along the wheel path which is often found to have upheavals on either side of the depression. Rutting of pavement will cause other problem such as rainwater accumulation. This water accumulation process will cause hydroplaning to occur. A water layer is built between surface of tyre and road surface, this leads to a loss of friction between the tyres and road surface, which is a potential hazard for the drivers on the road.

According to Suaryana & Sofyan (2019), rutting is the surface decline in the wheel tracks which is due to plastic deformation on pavement or subgrade layers. This incident is generally result from compression and densification or consolidation and lateral movement or plastic flow of a pavement layer.

Rutting resistance of an asphaltic mixture can be determined by a laboratory test which is known as wheel tracking test. A simulated wheel track is applied on the asphaltic mixture to evaluate the permanent deformation characteristics of the asphaltic mixture. The rut depth of track is measured against the number of passes of the wheel on a tested specimen (Al-Salih, 2020).

According to the shear modulus and phase angle in the study, the rutting index of asphalt is calculated by $G^*/\sin\delta$ where G^* refers to complex shear modulus, and δ refers to phase angle. The greater the rutting index value, the more preferable the high-temperature stability of asphalt and the greater resistance to permanent deformation (Wang et al., 2020).

Shaffie et al. (2017) studied the evaluation volumetric properties and rutting performance of cup lumps rubber modified asphalt using Superpave methods. Prior to the preparation of the asphalt mixture specimen, the chosen aggregates should pass the tests required in the Superpave System. The tests included Flaky and Elongated particles test, abrasion test, and Aggregate Impact Value (AIV) test. The percentage of the cup lump to be used as modifier and the Optimum Binder Content (OBC) is also determined, where it has great potential to improve the physical properties and the performance of the mix. Hence, the wheel tracking test is performed. The specimens are placed into the compactor to test for 8,000 numbers of cycles which is 60 cycles per minute. The rut depth of the result specimen is examined and measured. From the results, it is shown that the modified sample shows more resistance towards rutting compared than that of the unmodified sample with a smaller value of rut depth. This is because the elastic properties of the cup lump rubber particle enhanced the rutting resistance of the modified asphaltic mixture.

2.3.2 Resilient Modulus (M_R)

According to Xiao & Amirkhanian (2008), resilient modulus is a crucial material property to the elastic modulus which can be used to predict the response of a material when subjected to repeated impulses or moving loads particularly imposed load from vehicle tires on a road surface. A resilient modulus test was conducted to determine the stiffness modulus of asphaltic mixtures by indirect tensile test in accordance with ASTM D 4123 (ASTM, 1995). A study in India showed that the fatigue life of rubberised asphaltic mixture increased with higher resilient modulus value and lower percentage of air voids and initial strain of the mixture (Al-Sabaeei et al., 2019).

Previous research indicated there are certain factors will likely influence the response of asphaltic mixtures under repetitive load. The factors are materials type, test temperature, volumetric properties, load magnitude, frequency of loading, instantaneous and total deformation, cycle rest period, load duration, and specimen dimensions. The resilient modulus of the mixture can be computed by using Equation 2.1a and 2.1b in accordance with ASTM D 4123 (Xiao & Amirkhanian, 2008).

$$M_R = \frac{P(v + 0.2734)}{tH} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{Equation } 2.1a$$

$$v = 0.359\frac{H}{V} - 0.27 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{Equation } 2.1b$$

where;

M_R = Resilient Modulus
P = Load, Newton (N)
v = Poisson ratio
t = Thickness of specimen in mm
H = Recoverable horizontal deformation, mm
V = Recoverable vertical deformation, mm

Based on Suaryana & Sofyan (2019), most asphalt mixtures are not perfect elastic in most condition. This is because asphalt mixtures will deform under repetitive load. However, if the load applied on the asphalt is small compared to the strength of material, the deformation of the asphaltic mixtures can be recovered. Hence, the material is considered as elastic. In this research, the resilient modulus test is done by direct tensile test. The mains factors to be concerned in resilient modulus testing are loading frequency and temperature (Suaryana & Sofyan 2019). This is because these factors had a great impact on the resilient modulus value.

2.3.3 Dynamic Creep

Dynamic creep test or unconfined repeated load axial test which is performed by using the Universal Testing Machine (UTM) with specific dynamic creep fixture (Azahar, et al., 2019). This test was carried out to analyse the densification of a pavement, and the characteristics of pavement under repeated load and the pavement susceptibility to permanent deformation. According to Moghaddam et al. (2014) when a load are applied to an asphaltic mixture, it deformed. However, most of the deformation will recovers when the applied load are removed. This incident is caused by the visco-elastic properties of the asphaltic mixture. Nevertheless, there are still certain extend of the deformation that cannot be recovered. This deformation will be noticeable after specific number of load cycles.

A research had been done by Azahar et al. (2019) stated that the Cup Lump Rubber Modified Asphaltic Mixture produced a better creep modulus compared than that of the Conventional Asphaltic Mixtures. This is due to the properties of the rubber had increased the resistance to permanent deformation, which is explained in Figures 2.4 and 2.5, respectively.

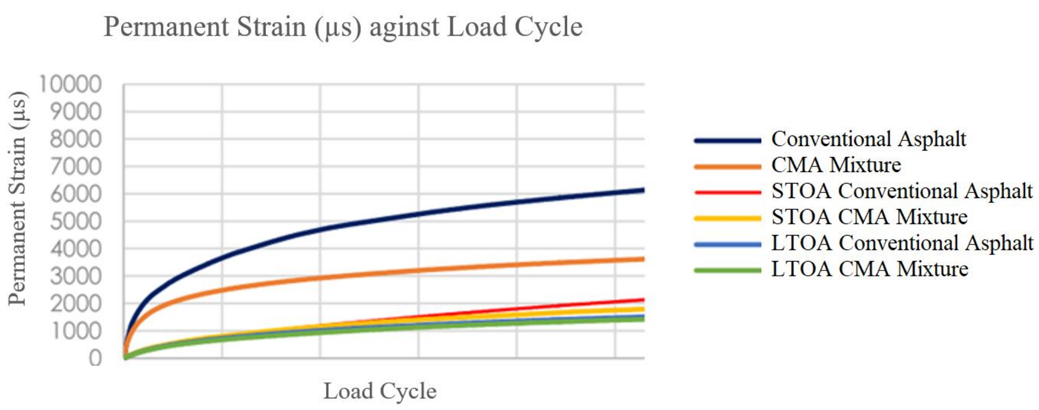

Figure 2.4 Cumulative strain of conventional and CMA mixture (Azahar et al. 2019)

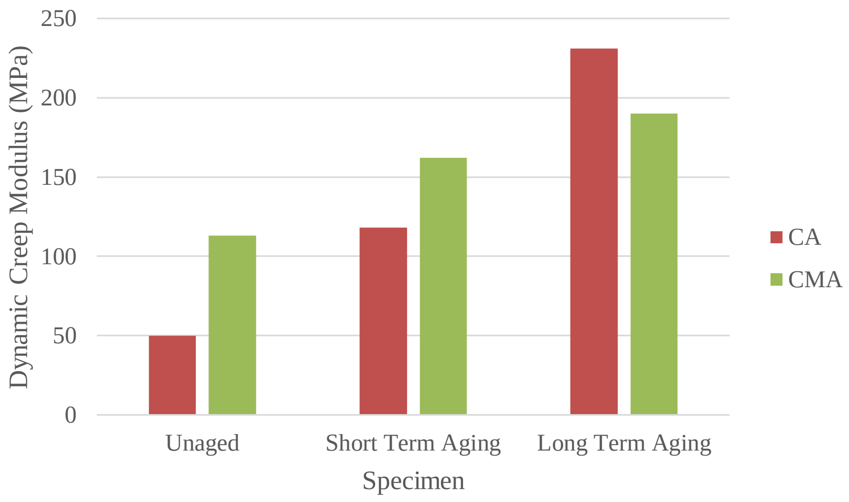

Figure 2.5 Dynamic Creep modulus of specimens (Azahar et al. 2019)

Figure 2.4 depicts the permanent strain produced against the load cycle for different type of asphaltic mixtures. In this research, it showed that the CA produced the highest strain which indicated that it does not perform very well in dynamic creep test. However, in the case of the CRMA it performed much better compared to the CA. However, Figure 2.5 showed the dynamic creep modulus for the CRMA is much higher than that of the CA. Thus, it can be claimed that the CRMA perform better than that of the CA in term of dynamic creep from the figures above.

Dynamic creep modulus of bituminous concrete is denoted by E* where it is a variation of the Young's elastic modulus E due to it being no longer elastic and it is viscoelastic, comprising matrix of elastic aggregates held together by asphalt (Badaruddin, 1995). The definition of young modulus is stress over strain. However, its relationship does not relate to viscoelastic substance such as asphalt. Thus, dynamic creep modulus differs from the young modulus, and it is also dependent on the temperature and rate of loading. On some occasion, the dynamic creep modulus is also known as complex modulus. For simplicity E* is referred to dynamic modulus and it is given by the Equation 2.2 below:

$$E^* = Se^{i\theta} = S\cos\theta + i\sin\theta \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Equation\ 2.2$$

where;

S = *Stiffness Modulus of Bituminous Materials*
θ = *Phase or lag angle*
I = *Complex Number*

A research had been done by Khedaywi & Mashagbeh (2017) which is about the effect rubberised asphaltic mixture on dynamic creep. The study considered five samples with different percentage of rubber modifier, 3 temperatures, 3 load frequencies (Hz), and air voids. The researcher developed a mathematical equation for the parameters used in the analysis (Equation 2.3).

$$Rut = 0.238 - 0.059\,Rub - 0.072\,AV + 0.314\,Temp + 0.236\,Hz \ldots Equation\ 2.3$$

where;

Rut = *Rut depth in (mm)*
AV = *Air Void (%)*
Rub = *Rubber Content (%)*
Temp = *Temperature (5, 25, 40 ^{o}C)*
Hz = *Load frequency (1, 4, 8 Hz)*

The researcher concluded that the 10% and 15% of rubber contents enhanced the resilient modulus and creep stiffness of the mixtures. This is attributed by better adhesion between the asphalt film and aggregate surfaces. Additionally, the temperature and frequency have a significant effect on the resilient modulus and creep stiffness. Accumulated strain increased as the temperature and loading frequency increased.

After the dynamic creep test, a dynamic creep curve of the specimens can be obtained automatically from the data logger. A dynamic curve consists of two part which is known as primary and secondary stage. The primary stage represented the recoverable elastic strain due to densification whereas the secondary part of the curve refers to visco-elastic strain caused by cumulative axial strain. A sample with a higher accumulated strain indicates asphalt pavement that is less resistance to permanent deformation. Figure 2.6 shows a graph that relates to cumulative permanent strain against load cycle conducted by Katman et al. (2015). In this research, the accumulated strain and ultimate strain of the modified sample is remarkably lower compared than that of the control sample. Hence, it can be concluded that the rubber modified asphaltic sample is less prone to rutting.

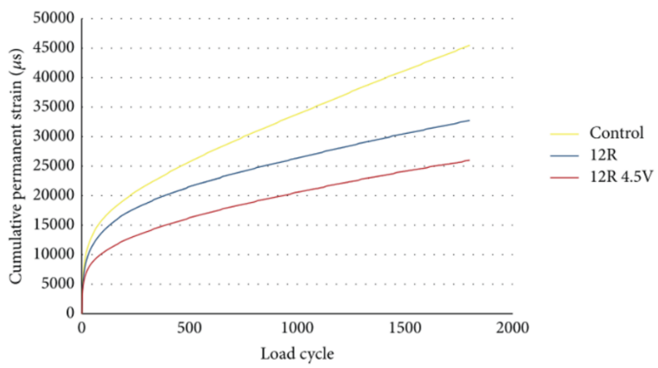

Figure 2.6 Dynamic creep curve for the research done by (Katman et al., 2015)

2.3.4 Marshall Mix Design

According to Annisa et al. (2020), Marshall mix design is a series of procedures and tests in order to obtain the OBC of the asphaltic mixture, and also to determine the plastic flow and the stability of the asphalt mixture. Marshall mix design begin with compaction of the asphalt specimens in a mould by using a manual to automatic compactor followed by cooling of the sample in water bath. Marshall mix design consists of five parameters namely density, stability, flow, percentage of air voids, and the percentage of voids filled with bitumen (VFB).

The density of the mix is the unit weight of the asphaltic mixtures. Density of the mix is crucial to ensure the asphaltic mixture to have enough strength to withstand the traffic load. In general, density of the asphaltic sample increase with the binder content until it reaches to a maximum. This is because the voids in the asphaltic sample are filled by those bitumen particles and higher bitumen content increases the unit weight until it reaches OBC. If excess bitumen are added to the asphaltic sample, the density of the sample will decrease instead. This is because when the binder is excessive, binder would replace the aggregate within the mixture, hence reduce the mix density due to the specific gravity of binder is lower than aggregate. The formula to calculate density of the mix is in Equations 2.3 and 2.4.

$$Bulk\ Specific\ Gravity = \left[\frac{Mass\ in\ Air}{Mass\ in\ Saturated\ Surface\ Dry - Mass\ in\ water}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq\ 2.3$$

$$Specific\ Gravity\ of\ Mix = \left[\frac{100}{\frac{P_{bit}}{G_{bit}} + \frac{100 - P_{bit}}{G_{agg}}}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq\ 2.4$$

where;

P_{bit} = Percentage of Bitumen
G_{bit} = Specific Gravity of Bitumen
G_{agg} = Specific Gravity of Aggregates

Stability of asphaltic mixtures is its ability to resist shoving and rutting under repetitive loads. A stable asphaltic mixture able to maintain its shape and smoothness under repetitive load. However, for an unstable asphaltic mixture may rut or deform easily under repetitive load. The increase in stability is owning to the increase in the adhesion between the aggregates and the binders (Ogundipe, 2016)

It is known that bitumen has a viscous property. Thus, asphaltic sample with a greater portion of bitumen will have a greater flow value. Optimum flow is important to ensure that all the aggregates are coated with layer of binder without impairing the physical strength of the asphaltic mixtures. Optimum flow is the flow rate when the binder content is at an optimum content. Thick binder layer will cause the aggregates to slide over more often, and it increases the number of the weaker plane to fail. High bitumen content also causes the asphaltic sample will result in high deformation since high bitumen content will decrease the stability of the sample.

Air Voids are very important in determining the performance of an asphaltic mixtures. The materials can become stiffer and improve the rut resistance as the air void decrease (Siswanto, 2016). Distress such as rutting, bleeding, and others are normally found in sample with low air voids during production and placement process. However, the percentage of air voids should be controlled at an acceptable range. This is because with an excessive amount of air voids, the asphalt is less resist to moisture damage which have an impact on the performance of the asphalt mixtures. On the other hand, if the air voids are less than an acceptable range, the asphalt will have inadequate space for the expansion of the mixtures especially during hot weather. The formula of air voids is stated in Equation 2.5.

$$V_a = \left[\frac{(G_{mix} - G_{mb})}{G_{min}}\right] \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathit{Equation}\ 2.5$$

where;

V_a = Percentage of Air Voids

G_{mix} = Specific Gravity of Mix

G_{mb} = Bulk Specific Gravity

It is known that there are voids within the asphalt. However, these air voids can be filled with bitumen or binder. Hence, VFB refers to the percentage of the air voids which are filled with bitumen or binders. The percentage of voids filled with bitumen is calculated using Equations 2.6. and 2.7.

$$VMA = 100 - \left[\frac{G_{mb} \times (100 - P_{bit})}{G_{agg}}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathit{Equation}\ 2.6$$

where;

VMA = Voids in Mineral Aggregates
G_{mb} = Bulk Specific Gravity
P_{bit} = Percentage of Bitumen
G_{agg} = Specific Gravity of Aggregates

$$VFB = \left[\frac{VMA - (V_a)}{VMA}\right] \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathit{Equation}\ 2.7$$

where;

VFB = Percentage of Voids filled with Bitumen
V_a = Air Voids
VMA = Voids in Mineral Aggregates

2.4 Aggregates Characterization

To ensure the aggregates used in the asphaltic mixture comply with the standard, several aggregates characterisation tests should be conducted on the aggregates. The example of some aggregate characterisation tests are described in the following sub-chapters. Those tests are reviewed from several sources and standard which are as shown below:

Los Angelas Abrasion Value (LAAV) test is done to determine the hardness of aggregates that are used in highway pavement and to evaluate resistance of the aggregate against abrasion and mechanical degradation during handling, construction, and use. The Los Angeles Abrasion Value (LAAV) is defined as the percentage of the crushed aggregates that passing through 1.70mm sieve after taken out from the Los Angeles drum in accordance with ASTM C131 (ASTM, 2006). If the aggregates used have a high LAAV, then it is considered weak and tends to break and disintegrate when load are applied to them. On the other hand, when the tested aggregates have a low LAAV value, then the aggregates are considered as high strength and it is resisted against abrasion and disintegration. The maximum LAAV value stated in the specification is 25% in accordance with JKR standard specification for road works (JKR-SPJ-2008-S4).

Flakiness and Elongation Index Test is to determine the flakiness and elongation index of the aggregates. The Flakiness index of aggregates is the percentage by weight of particles whose least dimension (thickness) is less than 0.6 times of their mean dimension. This test is not applicable to sizes smaller than 6.3mm in accordance with BS 812 Part 1 (British Standard, 1989). The Elongation index of an aggregate is the percentage by weight of particles whose greatest dimension (length) is greater than 1.8 times their mean dimension, and this test is not applicable for sizes smaller than 6.3mm in accordance with BS 812 Part 1 (British Standard, 1989). Flat and elongated particles are more readily to lock up which making compaction more difficult because the locked up particle are more difficult to be reoriented during compaction process. Also, flat and elongated particles will also have a tendency to break during compaction process due to their weak and narrow dimension.

2.5 Bitumen Characterization

To ensure the bitumen used in the asphaltic mixture comply with the standard, several bitumen characterisations tests should be conducted on the bitumen. The example of some bitumen characterisation tests which are reviewed from several sources and standards are stated below:

The penetration test measures the vertical distance travelled or penetrated by the needle into the bituminous material under prescribed conditions (load, time, and temperature). This test assessed the consistency of the binder, in which determining the perfect binder grade to be used in different climate conditions in accordance with ASTM D5 (ASTM, 2005). The grade of the bitumen is normally defined from the penetration value of the bitumen. For instance, a 60 / 70 grade bitumen indicates the penetration value of the bitumen ranges between 60 and 70. According to a study done by Mashaan et al. (2011), the incorporation of the rubber in the binder can decrease the penetration value significantly. The rubber could increase the stiffness of the mix which causing the binder less susceptible to temperature which could increase its resistance to permanent deformation such as rutting.

Ring and ball is conducted to determine the softening point of a bituminous material. Softening point is defining as the temperature at which the bituminous materials attained a specific degree of softening. It is noted that the bitumen will soften while it is being heated up. The value of the softening point should be in the range of 49 ^{o}C and 52 ^{o}C in accordance with ASTM D36 (ASTM, 2020). According to Bahruddin et al. (2020), the incorporation of the cup lump rubber can increasing the softening point of the binder. He also stated that the softening point is directly proportional to the increase in the viscosity and cohesion. The viscosity and the cohesion of the binder also have a close relationship with the molecular weight where the increase in the molecular weight creates more obstacles on the binder when the test is being carried out. Consequently, more heat are required to soften the binder which resulting a higher softening point.

The properties of the bitumen allow it can be stretched to a certain length without causing any rupture. Thus, ductility of a bituminous material is the distance of the bituminous material which it can be stretched before it broke. The material is being stretched at a specific speed (5cm/min) and specific temperature (25 ^{o}C) in accordance with ASTM D113 (ASTM, 2007). A research had been done by (Mashaan et al., 2011) stated that the ductility of the binder will decrease with the increase of the rubber content. He also stated where an increase in the ductility causes increase in the elasticity and stiffness of the mix yet to increase its resistance to rutting. Also, the modified binder will became thicker compared than that of the unmodified binder.

Flash point is the temperature at which the bituminous material will ignite temporarily during heating when a small flame is brought in contact with the vapour. This is because when the bituminous material is heated up until a certain temperature, it will release a vapour which is easily to be caught to fire ASTM D92 (ASTM, 2018). This test might not be practical for the actual condition of the pavement in function. This is because the pavement will not be heated up until this point in the real condition. The flash point test serves as a safety precaution. This is to prevent the danger of fire ignition during the heating process of the bituminous materials. According to a study done by (Khalili et al., 2019), the flash point of the binder decrease as the rubber content increase. This is because rubber ignites at a lower temperatures compared to the bitumen. However, the decrease is relatively low. He also incorporated other rubber types to the binder but there are no significant different on the flash point properties compared to the previous rubber modified binder. Therefore, he concluded that there were no distinguish correlation between rubber type and flash point properties.

2.6 Summary

This chapter summarizes all the reviews from the literature study. Based on the literature studies, it can be seen that CRMA is a good replacement of the CA in providing greater performance and durability. This is because the presence of the rubber particles can act as a gluing agent to enable a stronger bond between the aggregate particle and between aggregate particle and rubber particle. Thus, the CRMA is less susceptible to deform under repetitive load. Thus, the performance of the CRMA in Hamburg Wheel Tracking test and Dynamic Creep test will likely to be enhanced. At the same time, the elastic properties of the rubber can increase the overall elasticity of the CRMA which improving the performance of the asphalt mixture in resilient modulus test.

Prior to the asphalt mixture are tested. Several characterization test should be done to ensure the aggregate, binder, and other materials are suitable to be used in the mix. This is to ensure that the materials used obey their specific standard as required. However, due to time constraint, those characterization tests are not done. Thus, characteristic of the materials are analysed based on literature studies and tests done by the supplier of the materials. The OBC of the CRMA and CA are also determined to obtain a minimum amount of binder to be used to produce an asphalt mixture which obey the standard require by each of the parameter.