EVALUATION OF HOT MIX ASPHALT MIXTURES CONTAINING RECLAIMED ASPHALT PAVEMENT AND CRUMB RUBBER

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ABSTRAK

Dalam tahun-tahun kebelakangan ini, getah serbuk (CR) telah digunakan secara meluas dalam turapan asfalt, banyak penyelidikan menunjukkan bahawa campuran asfalt getah (CR) adalah bahan yang mesra alam dan turapan asfalt kitar semula (RAP) adalah turapan asfalt lama yang telah dikeluarkan dari jalan raya dengan pengilangan atau penyingkiran kedalaman penuh. Penggunaan RAP dalam asfalt campuran panas (HMA) menghilangkan keperluan untuk melupuskan turapan asfalt lama dan memelihara pengikat asfalt dan agregat, menghasilkan penjimatan dan manfaat kos yang signifikan kepada masyarakat. Makalah ini membentangkan kajian mengenai HMA dengan campuran RAP yang berbeza dan perkadaran getah serbuk yang dilakukan untuk menilai sifat-sifat mekanik dan prestasi campuran asfalt yang mengandungi RAP yang berlainan nisbah getah serbuk. Kaedah rekabentuk campuran Marshall digunakan untuk menghasilkan campuran kawalan dan campuran asfalt yang mengandungi 40% RAP, 40% RAP 2% CR dan 40% RAP 6% CR selaras dengan Spesifikasi Jabatan Kerja Raya, Malaysia (JKR/SPJ/2008) untuk penggredan asfalt AC14 yang padat dan ujian parameter Marshall. Ujian aliran kestabilan dan aliran Marshall merupakan analisis yang dilakukan untuk memastikan keputusannya adalah mematuhi keperluan spesifikasi yang telah ditetapkan. Ujian modulus berdaya tahan telah dilakukan untuk mengukur ketegangan yang boleh dipulihkan bahan di bawah tegasan berulang tanpa mencapai batas kegagalan. Ujian rayapan dinamik dilakukan untuk mengukur potensi rantaian campuran asfalt. Keputusan yang diperolehi menunjukkan bahawa tidak terdapat perbezaan yang ketara dalam ujian kestabilan dan aliran Marshall, dan modulus berdaya tahan antara campuran asfalt dengan RAP, getah serbuk dan campuran kawalan. Hasil ujian menunjukkan campuran kitar semula adalah setara prestasi HMA konvensional dari segi kestabilan Marshall, ujian aliran dan modulus berdaya tahan.

ABSTRACT

In recent years, crumb rubber (CR) has been applied widely in asphalt pavement. Many researchers have indicated that crumb rubber (CR) asphalt mixture is an environmentally friendly material and Reclaimed Asphalt Pavement (RAP) is old asphalt pavement that has been removed from a road by milling or full depth removal. The use of RAP in hot mix asphalt (HMA) eliminates the need to dispose old asphalt pavements and conserves asphalt binders and aggregates, resulting in significant cost savings and benefits to society. This paper presents a study on HMA with different RAP mix and crumb rubber proportions carried out to evaluate the mechanical properties and performance of asphalt mixes containing RAP different proportions of crumb rubber. Marshall Mix Design Method was used to produce control mix and asphalt mixes containing 40% RAP, 40% RAP 2% CR and 40% RAP 6% CR in accordance with Specifications for Road Works of Public Works Department, Malaysia (JKR/SPJ/2008) for AC14 dense graded asphalt gradation and parameter Marshall test. Marshall stability and flow test was analysis performed to ensure that the result is compliance with specification requirements. The resilient modulus test was performed to measure recoverable strain of the material under repeated stress without reaching the failure limit. The dynamic creep test was performed to measure the rutting potential of the asphalt mixture. The results obtained showed that there was no substantial difference in Marshall stability and flow test and resilient modulus between asphalt mixes with RAP40, RAP40CR2, RAP40CR6 and the control mix. The test results indicated that recycled mixes performed as good as the performance of conventional HMA in terms of Marshall Stability, flow test and resilient modulus.

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LIST OF SYMBOLS

mm	Millimetre
kPa	Kilo Pascal
g	Gram
N	Newton
cm^3	Centimetre cubic
+	More
-	Less
±	More and less
%	Percentage
˚C	Degree Celcius

LIST OF ABBREVIATIONS

AC	Asphalt Content
ASTM	American Society for Testing and Materials
AR	Asphalt Rubber
ARS	Asphalt Rubber Stone
BS	British Standard
RAP	Reclaimed Asphalt Pavement
CR	Crumb Rubber
CRM	Crumb Rubber Modified
CRP	Crumb Rubber Powder
CW	Control Warm
FHWA	Federal Highway Administration
HDPE	High Density Polyethylene
HMA	Hot Mix Asphalt
JKR	Jabatan Kerja Raya
LVDT	Linear Variable Displacement Transducer
MQ	Marshall Quotient
NAPA	National Asphalt Pavement Association
RAC	Rubber Asphalt Concrete
SMA	Stone Matrix Asphalt
US	United State
UTM	Universal Testing Machine
VMA	Voids in Mineral Aggregates
WMA	Warm Mix Asphalt
WR	Reclaimed Warm

CHAPTER 1

INTRODUCTION

1.1 Background

The pavement industry has long emphasized the need to reuse RAP materials obtained from asphalt pavements that have been removed from road reconstruction or coating processes. According (Nataadmadja, Prahara, and Christian 2017), these materials can be crushed and filtered for use as a high quality and good aggregate. Therefore, many researchers are studying the RAP Aggregate for reuse in future road construction projects. The advantages of reusing RAP aggregate in road construction, it reduces the cost of materials and waste and has good performance when mixed with natural aggregates. However, the aggregate RAP has several disadvantages, such as the interaction questioned between virgin material and recyclable material and increasing the stiffness of the RAP binders. Thus, the economic and environmental principles of the use of RAP in the asphalt mixtures, it is found that using RAP can increase the resistance of rutting and conducting and mixing of other virgins.

Crumb rubber is easily accessible due to the sintering industrial waste material, indirectly making an effort to recycle unused material. According (Xiao et al. 2008), most laboratory and field experiments have shown that rubber asphalt concrete (RAC) generally demonstrates endurance, crack reflection, fatigue and slip resistance, and resistance to rutting not only in layers, but also in layers absorbing membrane pressure (Xiao et al. 2008). Now, various rubber sizes are used in mixes around the globe. In addition, studies show that fatigue behaviour is better than conventional mixtures and can improve endurance of asphalt. However, the influence of two by products (CR and RAP) mixed with virgin blend was not clearly identified. Specifically, the effect of rubber size or the kind of physical properties of recycled blends is not investigated in detail. Therefore, increasing the supply and increasing cost of materials, the use of RAP and CR is an appropriate way of preserving non-renewable, aggregate and bitumen resources used for asphalt mixtures

1.2 Problem Statement

Nowadays, a structural failure in highway pavements such as cracks and rutting have always been an issue in highway construction. It is because the pavement design life should be considered up to 10 years Therefore, the continuous demand on the construction materials lead to the depletion of natural resources and increase the waste materials. Based on statistic in National Asphalt Pavement Association (NAPA) in 2011 the average amount of RAP used in asphalt mixtures nationwide increased from approximately 16% in 2009 to about 18% in 2010. The recycling of asphalt pavement materials is found to be the best method to minimize the usage of natural resources and to solve the materials disposal issues.

Moreover, asphalt cannot withstand drastic weather changes because asphalt is hard in cold environments and soft in hot environments. Previous studies showed that number of failures represented by the low temperature cracking, fatigue cracking, and the rutting (or permanent deformation) at high temperature, causing its quality and pavement performance to decrease. Therefore, the waste tyres which it is one of the environmental problems in Malaysia. This problem needs to be urgently solved because waste tyres are not easily disposed. Statistic from Ministry of Environment Malaysia stated that, waste tyres in Malaysia increase every year because the waste tyre is depending on amount of road user in Malaysia. Recycled the tyres will be the one of way to save the space.

Many studies have proved that RAP and crumb rubber could be incorporated into the pavement mixture. It is supported researcher by (Saberi.K, Fakhri, and Azami 2017), the influence of two by products (crumb rubber and RAP) mixed with virgin mixtures together has not yet been identified clearly. Especially, the effects of rubber size of recycled mixtures have not been investigated in detail.

Besides that, the waste material should be reuse to make other product instead of been disposed or burned it because this process will affect and destroy the nature environment. Sustainability of production systems is a key global issue for governments, industries and society, particularly in the timber processing and manufacturing sector. The purchase price of materials can also be one of the main determinants in deciding what material to use in construction projects. Apart from economic costs, costs derived from pollution and energy, as well as social aspects must be considered in choosing building materials.

1.3 Objective of Study

The aim of this study was determine the evaluation of hot mix asphalt containing reclaimed asphalt pavement and crumb rubber mixture. The aim was achieved through the following objectives:

i. To determine the effect of reclaimed asphalt pavement and crumb rubber to the asphalt mixture durability.

ii. To determine the effect of reclaimed asphalt pavement and crumb rubber in recoverable strain of the material under repeated stress of asphalt mixture.

iii. To determine the effect of reclaimed asphalt pavement and crumb rubber in rutting potential of the asphalt mixture.

1.4 Scope of Study

The scope of the study as follows:

i. HMA mixtures were designed by incorporating RAP and crumb rubber which are compatible with the conventional bituminous mixture.

ii. Mixture gradations used in this study were design in accordance to JKR (JKR, 2008).

iii. RAP and CR will have acted as aggregate replacement in RAP used 40% and different percentage crumb rubber used 2% and 6%.

iv. The size of RAP and crumb rubber replacement in asphalt mixture were below than 5 mm and 0.150 mm.

v. Grades of fresh bitumen (60/70 PEN) were utilized in this study.

vi. Performance of the mixtures was evaluated based on laboratory samples and tests.

1.5 Significant of Study

RAP is asphalt pavement removed from the reconstruction or replacement of a new pavement over the life of the pavement which ends. Whereas, crumb rubber is produced from the plant to be arranged and arranged to ensure that all waste must be prepared in appropriate conditions. Using wastes can minimize wastage in the industry and reduce environmental impact to the global.

Asphalt pavement is design to pavement preservation, provide road owners with a cost-effective way to preserve pavement life, correct minor distresses, and improve the performance and life of a road. When RAP and crumb rubber replace the percentage of aggregate, it totally will reduce the virgin aggregate and would be improving ride, and decreasing roadway noise.

This research is able to minimise the wastage of RAP and crumb rubber and also help the environment in context of waste industry. Thus, the idea of using replacement aggregate in new concrete production will minimise the asphalt pavement waste.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Referring all the relevant information from the previous thesis that can be related to the study such as RAP and crumb rubber that contributed to percentage of waste material in real life and related to the HMA mixture such as durability, recoverable strain of the material under repeated stress and rutting that can sustain asphalt mixture. All the explanation regarding to this matter will discuss in this chapter such as percentage of RAP and crumb rubber that will use to replace amount of coarse aggregate, fine aggregate and bituminous.

2.2 Background of Crumb Rubber

Waste tires constitute a serious environmental problem that many countries have to face as they accumulate rapidly and they are not easily disposed. In Malaysia the industrial upgrades and the use of cars are increasing as the road use rates in Malaysia are increasing. Therefore, the approach in treating and repairing conventional asphalt such as the introduction of additives to improving the road, is considered from year to year. The use of powder rubber from tires in asphalt, obtained from the term asphalt rubber was an alternative to minimize their ecological effects and at the same time, to improve the mechanical properties of asphalt mixtures (Fontes et al. 2010). Many studies have proved that CRM asphalt pavement increase pavement life by resistance to cracking and rutting, decrease traffic noise, and overall reduction of the maintenance costs. In addition, some researchers have found that the use of crumb rubber into asphalt binders can enhance the fatigue resistance (Vural Kök and Çolak 2011), (Wang et al. 2012), (Wang et al. 2013).

The main techniques for processing crumb rubber in asphalt are divided into dry and wet processes. Rubber used in the wet process is usually a fine material with 100 percentage passing 2 mm or smaller filter, which is added directly into the bitumen to provide the modified binder (Eskandarsefat et al. 2018). Generally, both laboratory tests and in situ test results showed that the modified mixed CR dry process showed poor performance or showed a slight improvement over the wet process or conventional asphalt mixtures (Abdul Hassana et al. 2014), (Eskandarsefat et al. 2018). Several laboratory studies have been conducted to determine the appropriate aggregate grading, the design bitumen content or the mix preparation procedure, which shows a better and consistent result for a dry process based mix (Cao 2007), (Eskandarsefat et al. 2018). On the contrary, the absence of specific standards, test methods and practice application manuals create controversy among researchers and customers regarding the inclusion of CR through dry processes (Eskandarsefat et al. 2018).

According (Mashaan et al. 2013), the earliest experiments that have involved incorporating natural rubber into asphalt binders to improve its engineering performance properties in the 1840s and in 1843, the asphalt modification of natural and synthetic rubber was introduced. In 1923, the natural and synthetic rubber transformers in bitumen improved and the development of rubber bitumen materials used as sealing, patch, and membrane joints began in the late 1930s. The first attempt to convert bitumen binder by adding rubber was made in 1898 by Gauedmberg, which has patented the rubber bitumen making process. Application for refined asphalt pavement began in Alaska in 1979. Placement of seven 4 lane km rubber pavements using the Plus Ride dry process between 1979 and 1981 was reported. The performance of this section is related to mixing, compaction, durability, fatigue, stability and flow, and the tires' pull and pulling resistance are illustrated. Rubber bitumen using wet processes was first used in Alaska in 1988 (Mashaan et al. 2013).

In Malaysia, the first record trial using rubber bitumen technology was reported in 1988, and the wet mixing process was used with a mixture of latex additives in the bitumen binder. In addition, the production of Malaysian garbage tires is about 10 million pieces annually, and unfortunately they are disposed of in a non-environmental way. In order to minimize pavement damages such as crack resistance, so the asphalt should be modified with selected polymer such as powder rubber transformer (CRM), and it will definitely benefit the environment as well as improve bitumen properties, durability, and reduce recovery costs (Mashaan et al. 2013).

2.3 Background of Reclaimed Asphalt Pavement

Aggregate reclaimed asphalt is an aggregate obtained from asphalt pavements that have been removed from reconstruction or coating processes. Where the use of RAP has grown into routine practice almost worldwide. These materials can be crushed and filtered for use as high quality aggregate, well measured (Nataadmadja et al. 2017). In the United States, Federal Highway Administration (FHWA) reports that 73 of 91 million metric tonnes of asphalt pavements are produced annually during refinement and widening projects are re-used as part of new roads, roadways, shoulders and ponds (Xiao et al. 2008). Additionally, aggregates and binders from old asphalt pavements are still valuable even if these sidewalks have reached their end of service life (Eskandarsefat et al. 2018). Currently in many construction projects asphalt is recycled in unbound base layers, used for road shoulders and rural roads, mixed for cold or hot in place recycling, and added in a relatively small percentage to new Hot Mix Asphalt (HMA) or Warm Mix Asphalt (WMA) (Eskandarsefat et al. 2018). They have been used, for years, with virgin aggregates and binders to produce new asphalt pavements, proved to be economical and effective in protecting the environment. However, the aggregate RAP has several disadvantages, such as the interaction questioned between virgin material and recycled materials and the increased stiffness of the RAP binder (Pradyumna, Mittal, and Jain 2013). Reclaimed asphalt pavement had created new pavements with substantial savings in materials, money, and energy.

The use of (RAP) in pavement construction has been becoming an extensive concern since the 1970s. Generally, RAP contains 4% - 6% asphalt binder by weight, so the use of RAP in asphalt pavement could reduce the consumption of virgin asphalt binder and virgin aggregate, which provide great economic and environmental benefits (Zhang et al. 2017), (Xiao et al. 2008). According to a DOT study, early 1990s, it is estimated that more than 90 million tonnes of asphalt pavements are withdrawn each year, and over 80 percent of RAPs are recycled, making asphalts the most frequently recycled material and surveys of NAPA, about 68.3 million tonnes of RAP has been reused or recycled directly into the pavement in 2012 (Song, Huang, and Shu 2018).

A survey in 2011 (Copeland 2011) showed that more than 40 states in the US allowed the use of more than 30% RAP in asphalt mixtures. However, the average RAP use was still less than 20% (Copeland 2011). Low percentage use of RAP cannot fully bring tremendous environmental and economic benefits. The use of high percentage RAP is still treated with great caution. Several disadvantages have hindered the widespread use of the high-RAP content asphalt mixture (Copeland 2011), (Song et al. 2018). First, after the blending between virgin binder and RAP binder, the binder quality is very complicated which affects the binder and mixture performance. In addition, the stiffness of the mixture incorporated with RAP is generally larger, which may lead to insufficient cracking resistance performance.

2.4 Advantage using Crumb Rubber and RAP for Civil Engineering

For the modern road infrastructure engineer the concept of sustainability often requires to focus on various main design aspects economic, environmental and architectural. In recent years the trend is to reduce the cost of construction, maintenance and the negative externalities (habitat fragmentation, noise and air pollution, landscape alterations) caused by the new infrastructure on the surrounding environment and the population (Dondi et al. 2014).

Some of the advantage in civil engineering application using RAP and crumb rubber are:

i. RAP and crumb rubber used in concrete
ii. RAP and crumb rubber used in asphalt pavement
iii. Crumb rubber used in highway crash barriers
iv. Septic tank leach field and other used in crumb rubber.

The use of secondary techniques that use raw material repeatedly will have the same effect as the original material. That is, replacing a few percent in the use of virgin raw materials and promoting recyclable materials. A large number of innovative and environmentally friendly materials have been launched in the market, and others are still under study, with stepping on the very important ingredients. In the field of road engineering, the use of recyclable materials has become significant due to the limited availability of aggregates and the inconvenience and excessive disposal costs for milling materials.

2.5 Mix Design of RAP and Crumb Rubber Content Incorporating Mixture

There are evaluations of mixture can be used to incorporate crumb rubber and RAP into mixture. Some previous studies have been studied and determination of RAP and crumb rubber content in hot mixture asphalt.

A previous researchers, by (Saberi.K et al. 2017) aim to investigate using three green technologies, including rubber asphalt, reducing asphalt pavement and hot mix asphalt to develop green pavement with minimal impact on the environment. In the current study, seven different mixtures were selected, including one control sample and six other samples, and modified by the different percentages of RAP and crumb rubber powder. Thus, with respect to the literature in (Wang et al. 2013) this study, used a maximum size crumb rubber powder of 0.177 mm was selected. It is worth noting that the crumb rubber powder was derived from end of life tires through ambient method (Saberi.K et al. 2017). It was utilized by 10% and 20% as replacement natural aggregate. Similarity, the RAP was used as a replacement for natural aggregate in different percentages, 30% and 60% respectively.

However, in others previous researcher of two rubber types in experimental design. It is ambient and cryogenic. It is used one rubber content with 10% by weight of virgin binder and one RAP content with 25% by weight of the modified mixture. The used a different of crumb rubber size, it's 0.425 mm (40 mesh), 0.600 mm (30 mesh) and 1.350 mm (14 mesh). For the RAP material size used in this study, passing 12.5 mm and 4.75 mm sieve are referred to as ± 4 RAP respectively. In this study, the RAP was taken from the same geographical area as the new aggregates to ensure that the aggregates in the RAP have similar properties to the virgin aggregates. The asphalt binder content of the -4 RAP was significantly greater than that of the +4 RAP. The sieved RAP was used for testing sample preparation of the modified mixtures (Xiao et al. 2008).

In addition, in previous researcher, investigated and assessed the engineering properties of the fine rubber utilization method of a mixture containing 30% RAP with and without rejuvenated agent. It's considered the low elastic properties of mixtures with RAP as a matter of greater fatigue and thermal susceptibility, the research aimed for CR modification effects on mechanical and performance properties. As a comprehensive study the effectiveness of CR on acoustic properties, micro and macro texture of the pavement assessment were the field study objectives of this research. There were produced to investigated the feasibility of added CR 1% by weight of the aggregate in mixtures contained 30% RAP by the weight of total aggregate. The RAP size are used in this study is RAP passing the 12.5 mm and the 6.3 mm sieves are respectively referred to as coarse RAP and fine RAP. According to the chosen gradation, the RAP mixture contained 25% of fine RAP and 5% of coarse RAP to keep the trial grading similar to fully virgin mixture (Eskandarsefat et al. 2018).

2.6 Performance of RAP and Crumb Rubber Incorporating Mixture.

In evaluation of previous researcher was obtained result on mixtures workability, stiffness modulus, dynamic modulus, and rutting resistance. It is following major findings have been obtained.

In previous researcher discussed result used reclaimed asphalt pavement and crumb rubber material in warm asphalt mixture. The result showed the improving effect of RAP on Marshall Stability in presence of Sasobit. Therefore, discussed by this study, 30% and 60% of RAP samples had more resistance in comparison with the control sample, CW; also, adding 10% and 20% crumb rubber can even cause better resistance (Saberi.K et al. 2017). In additional, the dynamic creep test illustrated that the samples containing RAP have enough resistance against permanent deformation. So that the sample containing 60% RAP (WR60) provided more resistance in comparison with CW and WR30 samples. Furthermore, the combination of crumb rubber powder and 60% RAP even prepared more resistance such that no tertiary phase was observed (Saberi.K et al. 2017).

According researched by (Xiao et al. 2008), that stated the addition of RAP and rubber increases the resilient modulus values at various temperatures. Increasing rubber size results in a decrease in the resilient modulus values for modified mixtures regardless of rubber types. The mixtures containing ambient rubber had slightly greater resilient modulus values than those made with cryogenic rubber. However, in rutting resistance of HMA the both the crumb rubber and RAP obtained an important role in improved. These additional recycling materials significantly enhance the potential high temperature performance in HMA and are being encouraged for use in hot climates.

The evaluated from researcher (Gibreil and Feng 2017), in Marshall tests showed that addition of 5% HDPE and 10% CRP raised the Marshall stability and MQ value of the unmodified asphalt mixture by 32.92% and 57.84%, respectively. Furthermore, the HMA mixtures modified with HDPE and CRP exhibited better deformation resistances owing to their high MQ values and high Marshall strength (stability). However, in rutting depth decreased with increase in the HDPE and CRP contents. On the other hand, the dynamic stability increased when HDPE and CRP were added to the asphalt mixture. Further, the permanent deformation resistance (rutting resistance) increased with the addition of HDPE and CRP.

Based on discussion of researcher by (Yu et al. 2018), the test results on both the stiffness modulus and dynamic modulus were affected by the type of WMA additives. The performance of the ARS mixture is closest to that of the AR mixture.in additional, all AR and WAR mixtures studied in this research showed better rutting and fatigue resistances compared with the SMA mixture with PEN 60/70 binder, which has been commonly used in Hong Kong.

The addition of crumb rubber in researcher (Setyawan, Febrianto, and Sarwono 2017), had a thin surfacing hot mixture asphalt demonstrates increasing the value of Marshall Stability, Marshall Flow and decreasing the value of Marshall Quotient, porosity, hence giving better performance of the mixture. In addition, from the correlation analysis between the percentage of aggregate replacement by crumb rubber and the optimum bitumen content has the effect on reducing the optimum bitumen content, so reducing the use of conventional petroleum bitumen and become more environmentally friendly infrastructure construction.

The lastly evaluate about crumb rubber modified by (Mashaan et al. 2013), the stability is improved by adding CRM binders to the stone mix asphalt as better adhesion is developed. In comparison to the control mix (mix with 0% CRM), the values of Marshall stability were generally higher. Moreover, the stiffness modulus of SMA samples containing various contents of CRM is significantly higher in comparison with that of non-reinforced samples. And, recommendation from this studied to use of different types of aggregate, aggregate gradation, different mixing methods, and different compaction methods for further studies.

2.7 Summary

The weakness of the current method today, needed modifications or improvement because to avoid the maintenance work increase as an effect from the heavy load from road user rises every year .When the maintenance work increases, hence the cost will also increase to repair every road damaged effect from the road user and weather.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter interpret the method for preparation, the material that involved and the test to be conducted for all the specimens. In this chapter will briefly discuss about the material that involved to replacement the coarse aggregate and fine aggregate which is RAP and crumb rubber. The percentage of the replacement of coarse aggregate was 40% of the RAP and fine aggregate was 2% and 6% of the crumb rubber. The details for all the specimens for mixture design will be presented in this chapter. The methods to use for conducting the test were discussed through this chapter.

3.2 Flow of Research

Figure 3.1 show the methodology that was used for this study. The research start from collecting all related information regarding the Marshall Stability and flow test, rutting resistance and resilient modulus of RAP and RAP with crumb rubber until the result and analysis.

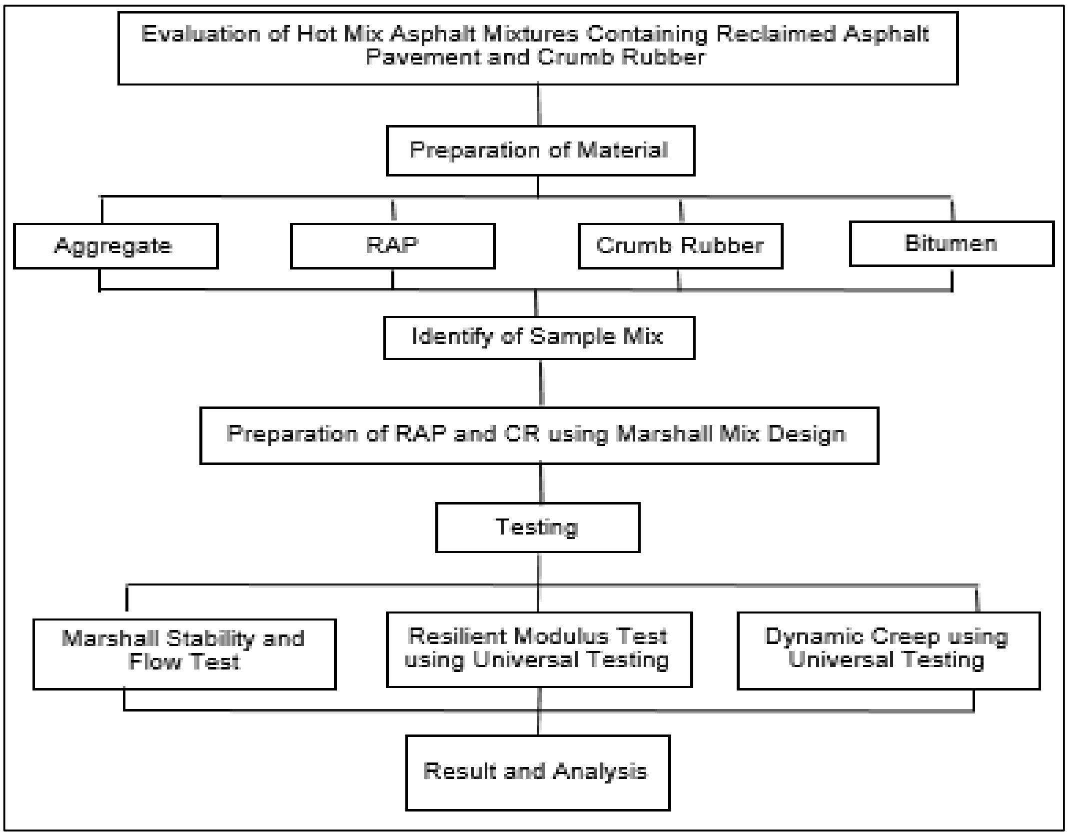

Figure 3.1 Flow Chart for the study

3.3 Material Properties

This part will have focused more on the raw materials needed for asphalt mixture design preparation. These kind of raw materials include aggregate, Reclaimed Asphalt Pavement (RAP), crumb rubber, and bitumen. The waste of RAP and crumb rubber will be replaced the percentage of coarse and fine aggregate by the weight. The entire materials were well arranged to avoid from any shortage when running the experiment and fulfil the requirement need.

3.3.1 Aggregate

Aggregates are mineral materials such as sand, stone, and stone which are destroyed for use as binder medium such as water, bitumen, Portland cement, lime and others to form compound materials such as pavement or concrete. For flexible and rigid pavements, it is used on the bases and sub-bases. The aggregate can be natural or made. Natural aggregates are generally extracted from larger rock formations through an open excavation (quarry). Extracted rock is typically reduced to usable sizes by mechanical crushing. Manufactured aggregate is often a by-product of other manufacturing industries. Hence, the particles that all passes through 14 mm sieve. All the specimens were sieved to obtain the required size for HMA mixture. Table 3.1 shows the weight of the aggregate used for AC14.

Table 3.1 Targeted weight of the aggregate

Mix Designation (BS Sieve Size (mm))	**AC 14**	**Selected Gradation (%)**	**Percentage of Weight of Aggregate (%)**	**Weight of Aggregate (g)**
14	90 – 100	95	5	56.90
10	76 – 86	81	14	159.32
5	50 – 62	56	25	284.50
3.35	40 – 54	47	9	102.42
1.18	18 – 34	26	21	238.98
0.425	12 – 28	18	8	91.04
0.150	6 – 14	10	8	91.04
0.075	4 – 8	6	4	45.52
Pan			6	68.28
Total				1138.00

Figure 3.2 Aggregate

3.3.2 RAP

RAP were used as a coarse aggregate in a HMA mixture. The RAP were sieved with size passes through 15 mm sieve. The amount of RAP modified has been expressed in the percentage which are 40% of total weight of aggregates per sample. All the specimens were sieved to obtain the required size for HMA mixture. Table 3.2 below show targeted weight of the RAP used for AC14.

Table 3.2 Weight of the RAP 40%

Mix Designation (BS Sieve Size (mm))	Weight of 40% RAP (g)	Weight of Aggregate (g)
5	284.50	None
3.35	102.42	None
1.18	68.28	170.7
Total	455.20	170.7

Figure 3.3 RAP

3.3.3 Crumb Rubber

Crumb rubber were used as a fine aggregate in a HMA mixture. The RAP were sieved with respect to the literature in (Wang et al. 2013) and (Saberi.K et al. 2017) which are used a maximum size crumb rubber powder of 0.177 mm was selected. Therefore, in this study the size 0.150 mm was selected. The amount of crumb rubber modified has been expressed in the percentage which are 2% and 6% of total weight of aggregates per sample. All the specimens were sieved to obtain the required size for HMA mixture. Table 3.3 below show the targeted weight of the crumb rubber used for AC14.

Table 3.3 Weight of the crumb rubber

Mix Designation (BS Sieve Size (mm))	Weight of CR 2% (g)	Weight of Aggregate 6% (g)	Weight of CR 6% (g)	Weight of Aggregate 2% (g)
0.150	22.76	68.28	68.28	22.76

Figure 3.4 Crumb rubber powder

3.3.4 Bitumen

All types of bitumen should be dry and free from dust. In the absence of water there is no practical problem of adjacent bituminous construction. The attachment problem occurs when the aggregate is wet and cold. This problem can be overcome by removing the moisture from the aggregate by drying and increasing the mixing temperature. Test principle is with diluted bitumen at 40°C for 24 hours. Hence, in this study, bitumen grade 60/70 PEN with 4.5% by weight of aggregate has been used as shown in Figure 3.5

Figure 3.5 Bituminous content with 4.5% by weight of aggregate

3.4 Preparation of HMA Mixture

3.4.1 Mix Design

To prepare standard specimen of asphalt for the determination of Marshall Stability and flow test, Resilient Modulus and Dynamic Creep test. This mix design was obtained with binder which used 60/70 PEN. In this study, the size of sieves of aggregate, RAP and crumb rubber has standardized according to the weight of sample in Table 3.1, 3.2 and 3.3.

3.4.2 Apparatus

The apparatus for Marshall mix design consist of Marshall compactor, mixer, water bath, Marshall compression machine, Marshall mould, sieve shaker and oven. Hence, in Figure 3.6 show a Marshall Compactor. The set of BS sieve size was shown in Table 3.1. Mechanical sieve shaker was to expose the aggregates to all the openings in a sieve that will separated the aggregate from the bigger to smaller of particles size. An oven with appropriate size with the temperature of 160 between 165°C was used to dry the aggregate and RAP.

Figure 3.6 Marshall Compactor

3.4.3 Procedure

Marshall samples was prepared based on ASTM D 1559. When the prepared of material which is aggregate, RAP and crumb rubber was sieve with largest opening sizes are placed above the ones that having smallest opening sizes. The samples were placed inside on the sieve with the largest opening which located on the top of the rest of sieves. The sieve was stirred up by mechanical apparatus for a sufficient period which is 10 to 15 minutes. A gradation of a material is important to determine the percentages and weight of material for every size according weight of sample. Table 3.1 shows the weight of the aggregate used for AC14The asphalt quantities weighed and incorporated into moulds of 101.6 mm in diameter with a height of 76.2mm and equipped with base plate and extension collar are heated in oven at 160 between 165°C for 24 hours.

To obtain a specimen shape, crater is formed in aggregate, binders are poured and mixed run so that all aggregates are coated. The mixing temperature should be within the temperature of 150 between 155°C. Then, a piece of filter paper is placed at the bottom of the mould and each mixture is poured into three layers with a rate of 25 blow per layer. And lastly, the mould is placed on the Marshall compactor with 75 blow. Specimens are carefully removed from the mould then marked.

Figure 3.7 Sample heated in oven.

Figure 3.8 Mixing sample at temperature 150 between 155°C.

3.5 Performance Test

3.5.1 Marshall Stability and Flow Test

This test was conducted on 12 samples with three samples for each sample mix of control, RAP40, RAP40CR2 and RAP40CR6 according to ASTM D6927 standard method. Prior to testing, the samples would be conditioned by placed in a water bath at a temperature of 60°C for 30 minutes. The sample would then be placed on the machine and will be loaded with force required for breaking the sample that would be measured as Marshall Stability and flow test.

Figure 3.9 Sample soaked in water bath

Figure 3.10 Marshall Test

Figure 3.11 Impact of load from Marshall test

3.5.2 Resilient Modulus Test

Resilient Modulus was used to as an index for evaluating temperature cracking of asphalt mixtures. The test was conducted in accordance to ASTM D4123 by using Universal Testing Machine (UTM) at controlled temperature of 25°C and 40°C. The peak load of 1000N was applied vertically in the diametrical plane of a cylindrical specimen and the horizontal deformation was measured. For this test, specimens were tested in two orientations, 0° and 90° as shown in Figure 3.13. As Poisson's ratio was assumed to be 0.35, thereby the Resilient Modulus was recorded in computer as show in Figure 3.14.

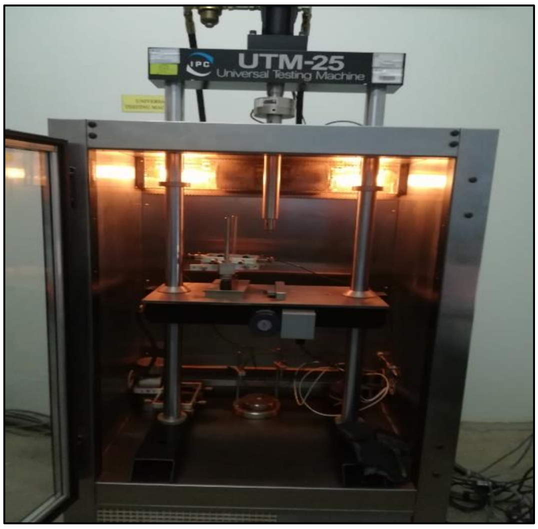

Figure 3.12 Universal Testing Machine (UTM)

Figure 3.13 Specimens tested in orientations

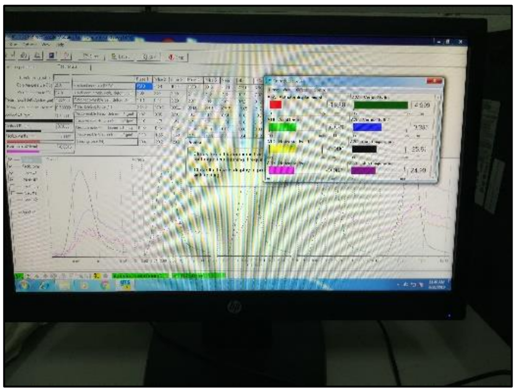

Figure 3.14 Data recording using software

3.5.3 Dynamic Creep Test

The test was conducted to determine the rutting potential of the asphalt mixture. The test was done by using the UTM machine and a software of permanent deformation on the computer. The sample would be conditioned at a temperature of 40°C in the machine before being placed into the dynamic creep apparatus. In setup condition sample, the conditioning period was a fixed thirty-minute time delay was programmed where the applied stress was set to zero as show in Figure 3.15. As the pulse of continuous loading, the strain was measured with two linear variable displacement transducer (LVDT). The testing occurred for about 1 hour and 30 minutes for tested 1800 cycles at stress levels of 10 kPa before the end result is produced on the computer.

Figure 3.15 Applied stress at sample

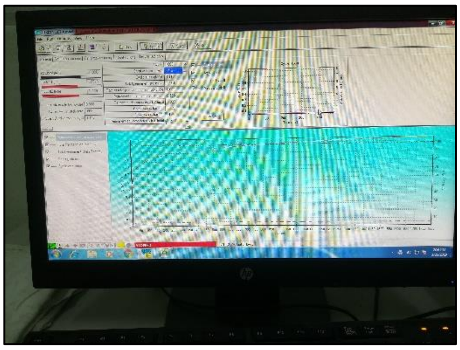

Figure 3.16 Test result as recoded by computer

3.6 Summary

The outcome from this chapter can determine from all the material that involve starting material preparation, preparation for method of testing for different types of specimen, and all the test was conducted to get the actual data. All the experimental data that obtained was analysed in the next chapter.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter the analysis process of all data obtained from laboratory work will be discussed in deeply. The result might be different from past researchers because of the quantity of replacement asphalt pavement and crumb rubber replacement by percent are not same. In this study, the percent of replacement asphalt pavement (RAP) and crumb rubber (CR) has been used is 0%, 40% RAP, 40% RAP and 2% crumb rubber, and 40% RAP and 6% crumb rubber from the total weight of aggregates. The replacement of RAP and crumb rubber in this study as a coarse aggregate and fine aggregate. Hence, Marshall stability and flow test, Resilient Modulus test and Dynamic creep test. Marshall stability and flow sets have been used to get information for density, stiffness, stability and flow. However, in dynamic creep test has produces result in deformation. Resilient Modulus test has been result.

4.2 Marshall Samples

Marshall sample was prepared based on ASTM D 1559. All the equipment and procedure for preparing the samples was referred at this standard. In this study, dry process was chosen for replacement of crumb rubber as fine aggregates by percent. 20 of samples were prepared to be tested by using Marshall samples.

4.2.1 Preparation of Sample

For the samples preparation there will be 30% rap, 30% rap 2% crumb rubber and 30% RAP 6% crumb rubber from the total weight of aggregates. The total weight of every sample is 1138.0 g excluded mould. Every sample has been poured and mixes with 4.5%

of bitumen grade 60/70 PEN. However, all samples will be prepared and tested according to the specification as a guide to attain that the laboratory works and materials fulfil the Malaysia Road works circumstances. The procedures of Marshall Mix Design were explained earlier in Chapter 3. The details of the mixes in this study were summarized as follows:

Table 4.1 Details of preparation process

Mix Characteristics		**Sample**			
		Control	**RAP 40**	**RAP40 CR2**	**RAP40 CR2**
Percentage of material (%)	Aggregate	100	60	58	54
	RAP	0	40	40	40
	Crumb Rubber	0	0	2	6
Binder Grade		60/70 PEN			
Binder Content (%)		4.5			
Compacting Machine		Marshall Hammer			
Marshall Compaction		75 blows			
Aggregate Gradation		AC 14			

4.3 Marshall Stability and Flow Test

From Marshall Stability and Flow Test the result of density, stiffness, stability and flow was obtained. The result of mixes sample was evaluated based on the quantity of RAP and crumb rubber replacement. The results of verified samples were recorded and shown in Table 4.3 for mix samples design after added percent of RAP and crumb rubber. However, all the modified asphalt needs to be check with JKR/SPJ/2008 Specification. Table 4.2 and Table 4.3 below shown all the parameters needed and the summary result were obtained from the testing.

Table 4.2 JKR/SPJ/2008 Specification

Marshall Parameter	**JKR/SPJ/2008 Specification**
Stability	> 8000N
Flow	2.0mm – 4.0mm
Stiffness	> 2000N/mm
Density	-

Table 4.3 Summary result

Sample No.	Bulk Density	Stiffness	Stability	Flow
Control	2.28	3115.88	11718.50	3.77
RAP40	2.32	6078.00	20744.58	3.42
RAP40CR2	2.23	5677.53	19071.66	3.37
RAP40CR6	2.09	3192.53	9935.64	3.69

4.3.1 Bulk Density Analysis

The bulk density of the sample is used to determine the specific gravity of a compacted HMA sample by determining the ratio of its weight to weight of an equal volume of water following ASTM D2726. The bulk density is decisively one of HMA characteristic because it used to calculate other parameter, such as air void, voids in mineral aggregates (VMA) and maximum density. Result for control mix of the bulk density is compared with modified content such as RAP40, RAP40CR2 and RAP40CR6. Figure 4.1 shows the result that the bulk density will increases of RAP40 with 2.32 g/cm^3. However, the decreases values of bulk density with the increasing of crumb rubber content. Thus, the result for control mix the bulk density is 2.28 g/cm^3 with compared to RAP40, RAP40CR2 and RAP40CR6 are 2.32 g/cm^3, 2.23 g/cm^3 and 2.09 g/cm^3.

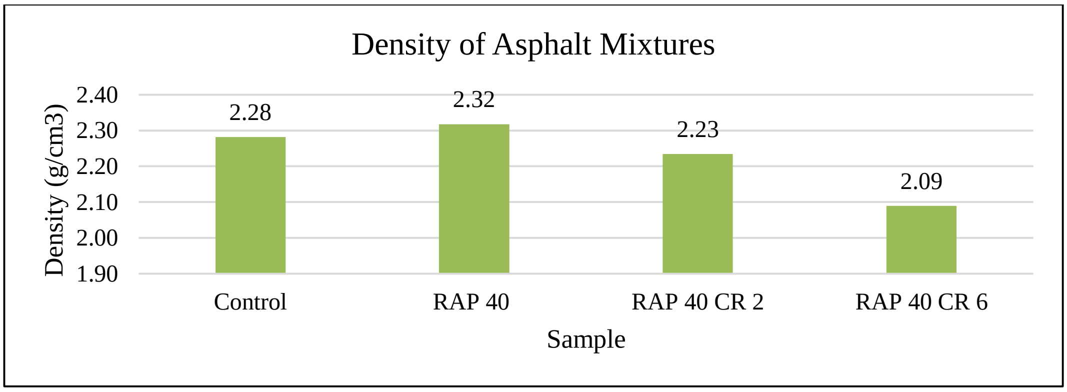

Figure 4.1 Bulk density of the asphalt mixtures

4.3.2 Stiffness Analysis

The measurement of the stiffness modulus is one of the methods used to understand the structural behaviour of bituminous mixes in roads (Vega-zamanillo et al.

2014). Figure 4.2 represented the data for stiffness at using 4.5% of binder content. It can be seen that the stiffness values of control, RAP40, RAP40CR2 and RAP40CR6 where are 3115.88 N/mm, 6078 N/mm, 5677.53 N/mm and 3192.53 N/mm already pass the JKR/SPJ/2008 specification in Table 4.2. So, RAP40 highest compare with other mixtures, represented that the stiffer the mix are less in the rut depth.

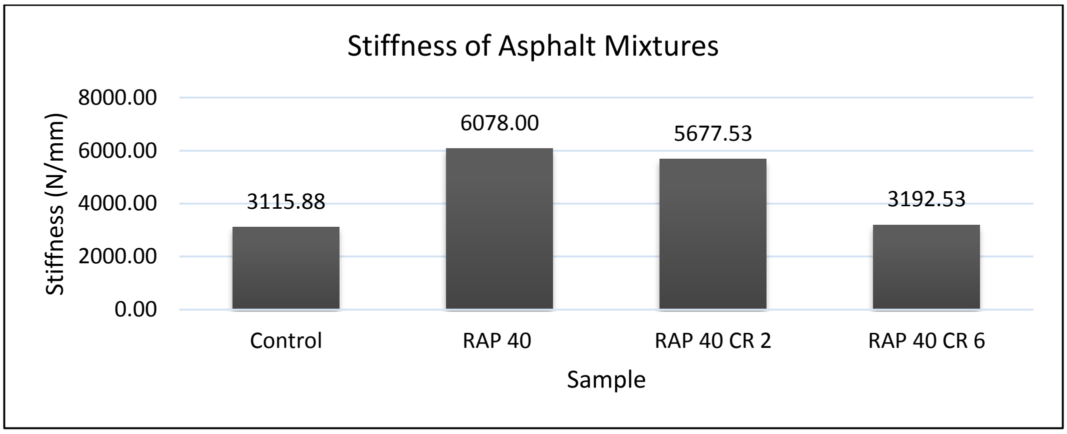

Figure 4.2 Stiffness of the asphalt mixtures

4.3.3 Marshall Stability

The stability test result is shown in Figure 4.3. The results show that the stability increases with RAP40 and thereafter RAP40 placed with different crumb rubber 2% and 6% are decreases. The stability of the mix with RAP40 was founded to be slightly greater than other mix. The stability values of the mixtures at percentage bitumen content of 4.5% were 20744.58 N respectively. It can be seen that the stability values for all mixtures met the JKR specification in Table 4.2 of not less than 8000 N. The results indicate that the asphalt mixture with RAP40 has been better than with control. The increase in stability can be attributed to improved adhesion between the aggregate and bitumen (Ogundipe 2016).

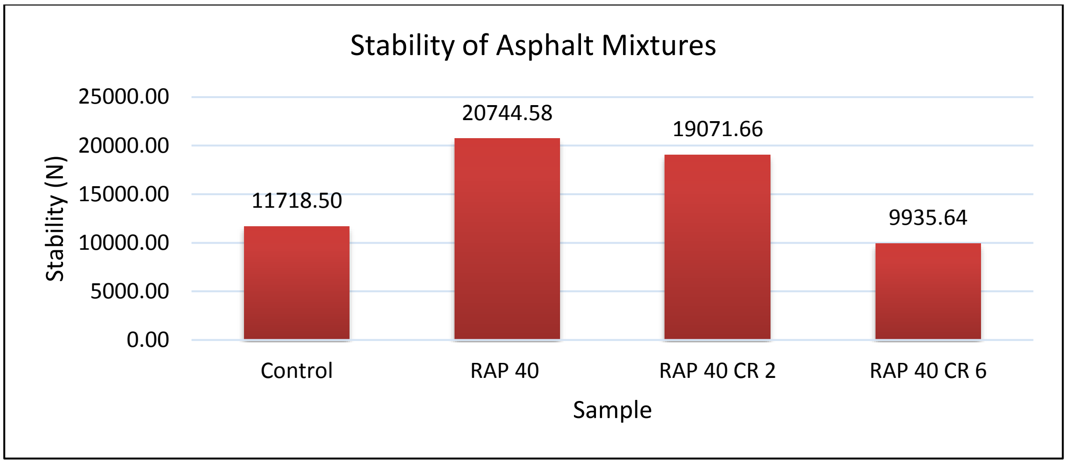

Figure 4.3 Stability of the asphalt mixtures

4.3.4 Flow Test

Flow is a state of vertical deformation of an asphalt mixture occurring as a result of a load imposed on the surface of the pavement and it is expressed in mm. Figure 4.4 represented the result of flow value of the asphalt mixtures. It can be seen from the results that the flow decreases than control mix. At flow value of the RAP40 and RAP40CR2 mix with 3.42 mm and 3.37 mm. The slight increase in flow value shows at RAP40CR6. It is also noted that, the result of mixtures met the specification of the JKR for roads must be in range 2.0 mm until 4.0 mm. It can be seen from the result of the sample that the flow value was in range specification. Therefore, the flow value may also be attributed to the use of different content in the mixture at 4.5% of binder content.

The higher the flow the more the permanent deformations such as rutting or shoving that tends to occur during its service life. However, a too low value of flow may indicate that a stiffer asphalt binder was used in the mixture, and it tends to produce cracks when high loads are imposed on the pavement. The minimum value of flow is needed to ensure the mixture has sufficient asphalt binder content and produced a stiffer mixture. The upper limit of flow 6 mm, was to ensure the mixture is not too soft to withstand the traffic load (Elsa, Eka et al. 2019).

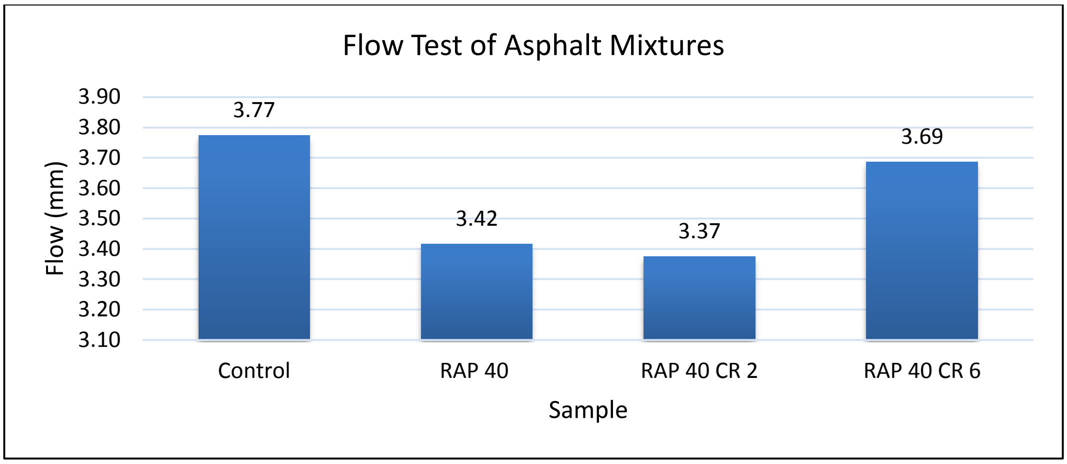

Figure 4.4 Flow of the asphalt mixtures

4.4 Resilient Modulus Test

Figure 4.5 shows the resilient modulus of the control and RAP and crumb rubber mixtures at 25°C and 40°C. Similar trends were observed at both test temperatures. RAP40 and RAP40CR2 exhibit higher resilient modulus compared with the control mixture at both temperature levels. However, at RAP40CR6 lower resilient modulus than control mixtures at both temperature levels. The 40% and 2% of RAP and crumb rubber mixture were 6567 MPa showed the highest resilient modulus, followed by 40% of RAP mixture were 4652.50 MPa, the control asphalt mixture were 4617 MPa and 40% and 6% of RAP and crumb rubber mixture were 1614 MPa at 25°C. Meanwhile, at 40°C, the resilient modulus of the control, 40% of RAP, 40% and 2% of RAP and crumb rubber and 40% and 6% of RAP and crumb rubber asphalt mixtures were 2116.50 MPa, 2763 MPa, 3596 MPa and 1378 MPa.

The results indicated that the 40% and 2% of RAP and crumb rubber mixture exhibits higher recoverability compared with the other mixtures after being loaded at medium and high temperature. The capability of the asphalt mixtures to recover to its original condition depends on elasticity of the bitumen. It's mean, the RAP40CR2 mixture achieved the highest resistance to rutting owing to its higher G (complex shear modulus) and lower d (phase angle) with bitumen. Meanwhile, G and d were reduced at low temperature, thus increasing resistance to fatigue cracking. Low d contributed to the elasticity of the bitumen, thus facilitating the return to its original condition. The contact between the modified bitumen and aggregate particles becomes stronger owing to strong bonding and high adhesiveness of the RAP and crumb rubber (Siti Nur, Amiera Jeffry Ramadhansyah et al. 2018). The stiffness and elasticity of the RAP40CR2 asphalt mixture were enhanced, resulting in improved performance of the RAP40CR2 asphalt mixture in terms of the resistance.

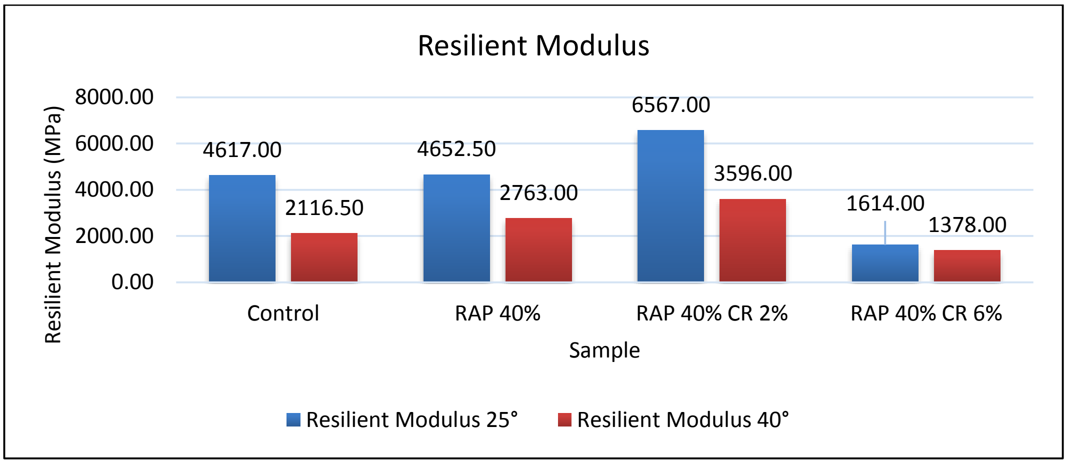

Figure 4.5 Result of different degree in resilient modulus testing

4.5 Dynamic Creep Test

Rutting evaluation at 40°C was carried out using dynamic creep test. It can be found that there are significant differences among these curves. Each dynamic creep curve consists of two parts, namely, primary stage and secondary stage. Primary stage presents recoverable elastic strain due to densification of the mixture while secondary stage shows viscoelastic strain resulted by cumulative axial strain. In this test, tertiary stage of specimen did not occur due to a short loading period of 1800 cycles except for control mixture tested at 400 kPa stress level and 50°C (Katman et al. 2015).

From this test, permanent strain and permanent deformation results were computed. Total permanent strain of control and RAP with crumb rubber modified HMA mixtures were calculated and compared with each other. Based on Figure 4.6, as can be seen in these figures, rutting resistance of RAP and crumb rubber modified mixture failed improved remarkably compared to the control mixture. All the sample modified mixture of total permanent strain are fail improved with increases at modified mixture. Hence, the 40% RAP and 2% crumb rubber (RAP40CR2) obtained the highest permanent strain compared with the other RAP and crumb rubber asphalt mixtures. The permanent strain affects the permanent deformation of the asphalt mixtures.

As can be seen in Figure 4.7, the RAP and crumb rubber asphalt mixture reached failure a highest permanent deformation compared with the control asphalt mixture. Given the similar permanent strain value of RAP40 and RAP40CR6, strain affects permanent deformation because the two samples overlapped at 1800 cycles and then the deformation of RAP40 was constantly lower than that of the RAP40CR2 asphalt mixture. It is worst mentioning that tertiary zone was observed for all sample showing the high resistance of the samples against the permanent deformation.

The creep stiffness for the tested mixtures is calculated according to Equation (2). The mean values of the creep stiffness are presented in Figure 4.8. From this figure it's obvious that the addition of the 40% RAP and 2% crumb rubber (RAP40CR2) has lowered the value of the creep stiffness for all mixtures sample contents. Also, the increase in the crumb rubber content in RAP increases the stiffness of the mixture and the 40% RAP has the highest value of the stiffness followed by 40% RAP 6% CR (RAP40CR6) and 40% RAP 2% CR (RAP40CR2) mixture.

These results were consistent with those of highest permanent strain and permanent deformation, with 40% RAP and 2% CR (RAP40CR2) mixture showing the owing to its lowest stiffness. These analyses showed that the 40% RAP and 2% crumb rubber (RAP40CR2) modified can increase the permanent deformation of the asphalt mixture compared with the bitumen content.

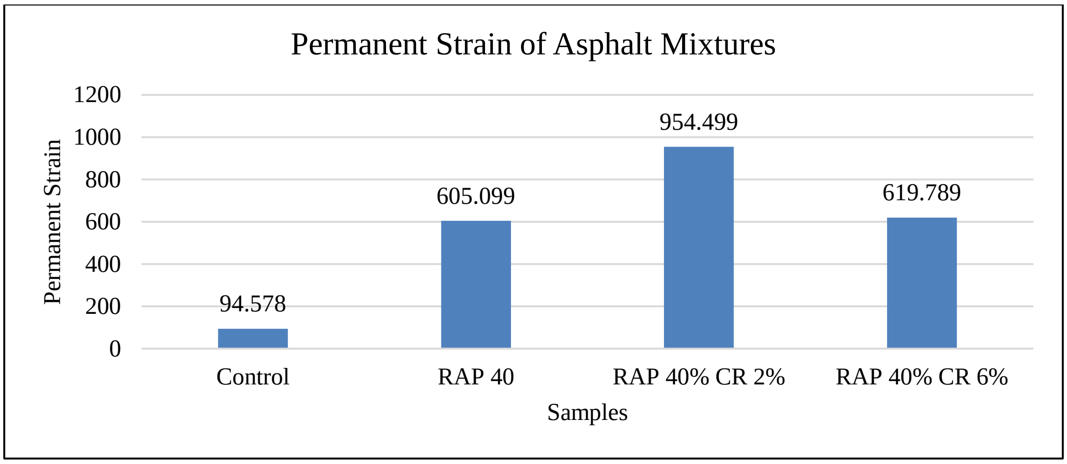

Figure 4.6 Permanent strain of RAP and CR modified asphalt mixture

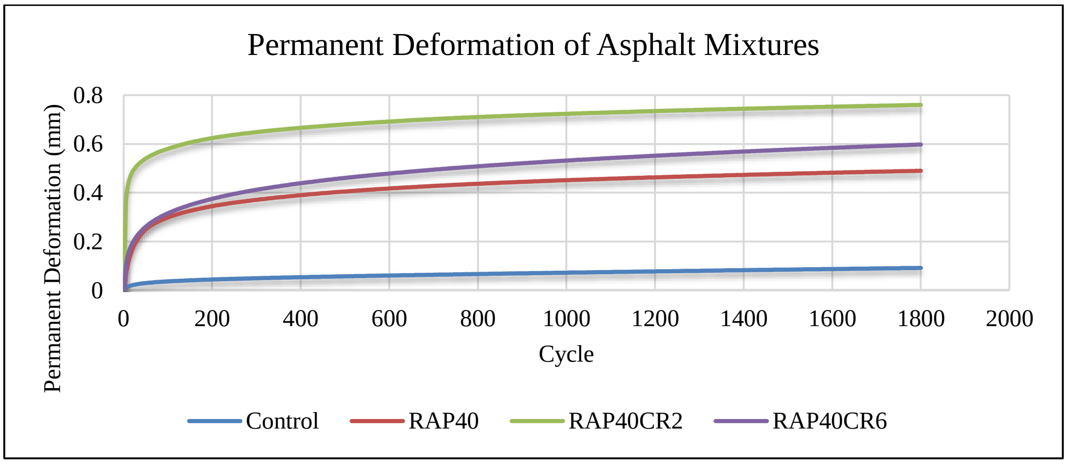

Figure 4.7 Permanent deformation of RAP and CR modified asphalt mixture

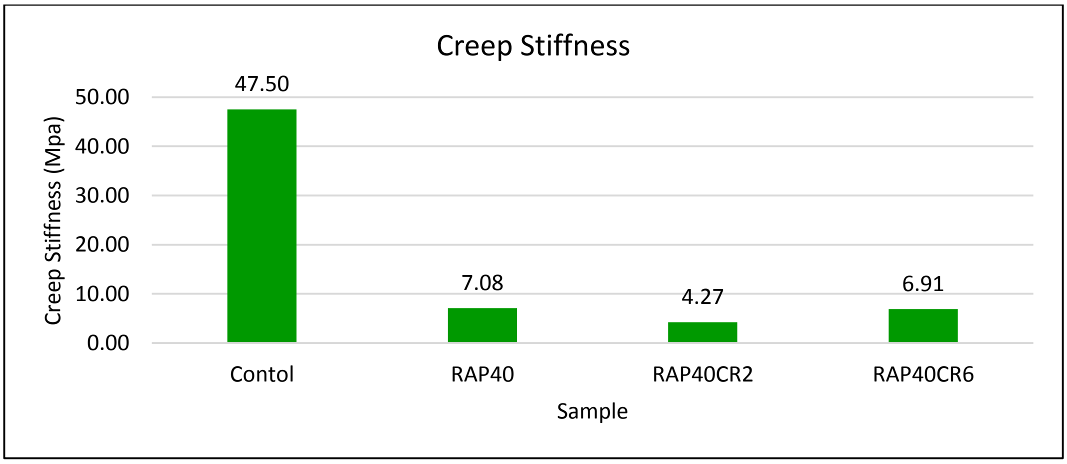

Figure 4.8 Creep stiffness of RAP and CR modified asphalt mixture

4.6 Summary

Overall, the chapter was discussed about the experiment result and discussion of this study. All the analysis of the data for control specimen and sample with different percentage of wood block was describe in details in this chapter. The content of woodblock that substituted in beam concrete was 6%. In the next chapter, conclusion and recommendation will be discussed to improve the result of the study.

CHAPTER 5

CONCLUSION

5.1 Introduction

This study was conducted to determine the strength and properties of the hot mix asphalt (HMA) with contained replacement asphalt pavement(RAP) and crumb rubber as replacement for aggregate and the different percentage replacement which are 40% RAP, 40%RAP and 2% crumb rubber and 40% RAP and 6% crumb rubber.

5.2 Conclusion

From the result obtained, the following conclusion can be drawn based on the objectives. The first objective for this study is to evaluate the effect on stability and flow used in hot nix asphalt contained the reclaimed asphalt pavement and crumb rubber as a coarse and fine aggregate. Based on the result, it can conclude the improving effect of 40% RAP on Marshall Stability had more resistance in comparison with the control samples, also adding 2% crumb rubber can even cause better resistance. However, adding 6% crumb rubber, it's was become decreased compare with the control samples and all sample was meet the requirement based on the standard specification of Public Work Department, JKR/SPJ/2008 whereas the minimum stability is 8000 N. Likewise, the flow test highest is control sample were 3.77 mm compared with other samples. However, all samples were meet the requirement specification of JKR whereas in range of 2 mm to 4 mm, so all the samples had in meet specification.

The second objective is to determine the effect of reclaimed asphalt pavement and crumb rubber in recoverable strain of the material under repeated stress of asphalt mixture. From the result obtained, it can have concluded that the ability of the asphalt mixture recovered to its original state after being loaded was shown when the resilient modulus was improved for both 25 C and 40 C temperatures. The capability of the RAP40CR2 asphalt mixtures achieved the highest resistance to recover to its original condition depends on elasticity of the bitumen.

The lastly objective is to evaluate the effect of reclaimed asphalt pavement and crumb rubber in rutting potential of the asphalt mixture. From the result obtained, it can have concluded that the permanent deformation, strain characteristics and creep stiffness of control and RAP and crumb rubber modified asphalt mixture were evaluated using dynamic creep test. The samples containing 40% RAP and 2% and 4% of crumb rubber (RAP40, RAP40CR2 and RAP40CR6) failure of resistance in comparison with control samples in permanent deformation. While, these highest strain and deformation owing to its lowest stiffness. Therefore, to achieve the best improvement for the modified mixtures properties and has a great effect in improving the resistance to the permanent deformation (Wazeri et al. 2017). Hence, the mixtures of contain Reclaimed Asphalt Pavement and crumb rubber are failure using Hot Mixture Asphalt in rutting potential.

Based on these findings, the objectives of the study have been achieved which is to determine the durability and recoverable strain of the material under repeated stress in coarse RAP and fine crumb rubber particle in difference percentage by replacing fine aggregate in Hot Mix Asphalt in percentage. All the overall findings referred to the JKR Specification which is JKR/SPJ/2008. However, in rutting potential of the Reclaimed Asphalt Pavement (RAP) and crumb rubber was not suitable to use in Hot Mixture Asphalt. It is because the RAP and crumb rubber weak in air void on relatively compacted of asphalt mixture.

5.3 Recommendation

There are a few recommendation and improvement that can be achieved and implement in the future to obtain the actual result with variety scope of study. This recommendation and improvement can be present as guideline and produce a lot of ideas in future studies. The recommendation for this study as follow:

i. Utilize a method of treatment process for the RAP such as wash the RAP before testing to acquire an accurate result or better than this study.

ii. Apply different percentage RAP and crumb rubber to investigate the strength can be same as natural aggregate. Thus, it might be reducing the usage of natural aggregate.

iii. It is recommended to investigate the effect of reclaimed asphalt pavement and crumb rubber powder on the performance of warm mix asphalt mixtures.

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APPENDIX A1
PREPARATION OF SAMPLE CONTROL

Size	Aggregate
14	56.90
10	159.32
5	284.50
3.35	102.42
1.18	238.98
0.425	91.04
0.15	91.04
0.075	45.52
Pan	68.28
Total	1138.00

APPENDIX A2
PREPARATION OF SAMPLE RAP 40%

Size	Nominal	RAP 40	Aggregate
14	56.9	none	56.9
10	159.32	none	159.32
5	284.5	284.5	none
3.35	102.42	102.42	none
1.18	238.98	68.28	170.7
0.425	91.04	none	91.04
0.15	91.04	none	91.04
0.075	45.52	none	45.52
Pan	68.28	none	68.28
Total		455.2	682.8

APPENDIX A3

PREPARATION OF SAMPLE RAP 40% AND CR 2%

Size	Nominal	RAP 40	CR 2	Aggregate
14	56.9	none	none	56.9
10	159.32	none	none	159.32
5	284.5	284.5	none	none
3.35	102.42	102.42	none	none
1.18	238.98	68.28	none	170.7
0.425	91.04	none	none	91.04
0.15	91.04	none	22.76	68.28
0.075	45.52	none	none	45.52
Pan	68.28	none	none	68.28
Total		455.2	22.76	660.04

APPENDIX A4
PREPARATION OF SAMPLE RAP 40% AND CR 6%

Size	Nominal	RAP 40	CR 2	Aggregate
14	56.9	none	none	56.9
10	159.32	none	none	159.32
5	284.5	284.5	none	none
3.35	102.42	102.42	none	none
1.18	238.98	68.28	none	170.7
0.425	91.04	none	none	91.04
0.15	91.04	none	68.28	22.76
0.075	45.52	none	none	45.52
Pan	68.28	none	none	68.28
Total		455.2	68.28	614.52

APPENDIX B
MARSHALL STABILITY TEST CALCULATION

MARSHALL TEST RESULT

TYPE OF MIX : PA GRADING B

BITUMEN : 70/80

SG_{eff} = 2.6 SG_{app} =

SG Bitumen = 1.03

SGBlended =

Volume	Corr	Kilonewton	Newton
		1.0	1000
509-522	1.00		
523-535	0.96		
536-546	0.93		

Sample No	% Content	Weight(gram)			Bulk Volume cc.	Specific Gravity		Volume - % Total			Voids (%)			Stability (N)			Flow (mm)	Stiffness (N/mm)
		In Air	In Water	SSD		Bulk	TMD	Bitumen	Aggregate	Voids	VMA	VFA	VTM		Measured	Corr. Stability		
a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s
					e-d	c / f		b x g / SGbit	(100-b)×g / SGag	100-i-j	100-j	100(i/l)	100-(100g/h)					
CONTROL	4.50	1177.60	656.10	1186.10	530.00	2.22								1.10	8219.00	9035.97	3.94	2291.65
	4.50	1180.60	671.70	1184.50	512.80	2.30								1.10	10374.00	11405.18	3.50	3256.76
	4.50	1221.10	698.30	1224.50	526.20	2.32								1.10	13384.00	14714.37	3.87	3799.22
	4.50					**2.28**	**2.44**	**9.97**	**83.71**	**6.32**	**16.29**	**61.18**	**6.32**			**11718.50**	**3.77**	**3115.88**
RAP	4.50	1159.20	665.20	1160.80	495.60	2.34								1.10	19615.00	21564.73	3.64	5926.00
	4.50	1174.10	668.30	1176.00	507.70	2.31								1.10	17880.00	19657.27	3.23	6091.50
	4.50	1160.40	658.60	1162.80	504.20	2.30								1.10	19112.00	21011.73	3.38	6216.49
	4.50					**2.32**	**2.44**	**10.13**	**85.03**	**4.84**	**14.97**	**67.65**	**4.84**			**20744.58**	**3.42**	**6078.00**
RAP CRUMB	4.50	1177.00	648.70	1179.50	530.80	2.22								1.10	15100.00	16600.94	2.78	5969.41
	4.50	1171.70	652.30	1174.90	522.60	2.24								1.10	19448.00	21381.13	3.67	5821.16
	4.50	1179.10	656.30	1181.80	525.50	2.24								1.10	17494.00	19232.90	3.67	5242.00
	4.50					**2.23**	**2.44**	**9.76**	**81.98**	**8.26**	**18.02**	**54.16**	**8.26**			**19071.66**	**3.37**	**5677.53**
RAP CRUMB	4.50	1169.80	585.50	1172.50	587.00	1.99								1.10	8892.00	9775.86	5.96	1641.35
	4.50	1185.20	634.60	1188.60	554.00	2.14								1.10	9306.00	10231.02	2.84	3599.94
	4.50	1147.10	613.30	1150.50	537.20	2.14								1.10	8914.00	9800.05	2.26	4336.31
	4.50					**2.09**	**2.44**	**9.13**	**76.65**	**14.22**	**23.35**	**39.09**	**14.22**			**9935.64**	**3.69**	**3192.53**

APPENDIX C
RESILIENT MODULUS TEST (25°C AND 40°C)

1. Resilient Modulus Test Control (25°C)
2. Resilient Modulus Test 40% (25°C)
3. Resilient Modulus Test 40% and CR 2% (25°C)
4. Resilient Modulus Test 40% and CR 6% (25°C)
5. Resilient Modulus Test Control (40°C)
6. Resilient Modulus Test 40% (40°C)
7. Resilient Modulus Test 40% and CR 2% (40°C)
8. Resilient Modulus Test 40% and CR 6% (40°C)

APPENDIX D
DYNAMIC CREEP TEST (40°C)

1. Dynamic Creep Test Control (40°C)

2. Dynamic Creep Test RAP 40% (40°C)

3. Dynamic Creep Test RAP 40% and CR 2% (40°C)

4. Dynamic Creep Test RAP 40% and CR 6% (40°C)