PROPERTIES OF HOT MIX ASPHALT BY REPLACING CRUMB RUBBER AS FINE AGGREGATE

NOOR LIYANA BINTI AHAZAR

B. ENG(HONS.) CIVIL ENGINEERING

UNIVERSITI MALAYSIA PAHANG

UNIVERSITI MALAYSIA PAHANG

DECLARATION OF THESIS AND COPYRIGHT

Author's Full Name : NOOR LIYANA BINTI AHAZAR

Date of Birth : 15 JULY 1992

Title : PROPERTIES OF HOT MIX ASPHALT BY REPLACING CRUMB RUBBER AS FINE AGGREGATE

Academic Session : 2016/2017

I declare that this thesis is classified as:

☐ CONFIDENTIAL (Contains confidential information under the Official Secret Act 1997)*

☐ RESTRICTED (Contains restricted information as specified by the organization where research was done)*

☑ OPEN ACCESS I agree that my thesis to be published as online open access (Full Text)

I acknowledge that Universiti Malaysia Pahang reserves the following rights:

1. The Thesis is the Property of Universiti Malaysia Pahang
2. The Library of Universiti Malaysia Pahang has the right to make copies of the thesis for the purpose of research only.
3. The Library has the right to make copies of the thesis for academic exchange.

Certified by:

_______________________ (Student's Signature)

_______________________ (Supervisor's Signature)

920715-08-6402
New IC/Passport Number
Date: 19 JUNE 2017

DR. FADZIL BIN MAT YAHAYA
Name of Supervisor
Date: 19 JUNE 2017

NOTE : * If the thesis is CONFIDENTIAL or RESTRICTED, please attach a thesis declaration letter.

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of B ENG (HONS.) CIVIL ENGINEERING.

____

(Supervisor's Signature)

Full Name : DR.FADZIL BIN MAT YAHAYA

Position : SUPERVISOR

Date : 19 JUNE 2017

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

____

(Student's Signature)

Full Name : NOOR LIYANA BINTI AHAZAR

ID Number : AA13043

Date : 19 JUNE 2017

PROPERTIES OF HOT MIX ASPHALT BY REPLACING CRUMB RUBBER AS FINE AGGREGATE

NOOR LIYANA BINTI AHAZAR

Thesis submitted in fulfillment of the requirements
for the award of the
Bachelor Degree in Civil Engineering

Faculty of Civil Engineering and Earth Resources

UNIVERSITI MALAYSIA PAHANG

JUNE 2017

ACKNOWLEDGEMENTS

First and foremost, I would like to express my deep gratitude and most heartfelt thanks to Allah S.W.T. for His Blessing, for lightening up my heart with the torch of knowledge and for giving me strength to finish this project.

With the utmost respect and pleasure, I would like to express my sincere thanks and appreciation to my supervisor Dr. Fadzil Bin Mat Yahaya, who continuously guided me throughout every step of my thesis work and generously shared his time and knowledge with me. I am greatly indebted to him for his encouragement and incessant help to achieve more than I expected of myself.

My dedication also goes to all technicians of Highway and Transportation Laboratory of UMP, for their collaboration. In particular, Mrs. Sarah, Mr. Sani and Mr. Amir for their assistance and helpfulness during my laboratory work.

Last but not least, I would like to take this golden opportunity to express my special thanks to my family, housemates, classmates and friends who tirelessly encouraged and supported me in countless ways to pursue my Degree.

ABSTRAK

Banyak penyelidikan telah dijalankan dalam mencari bahan lain sebagai alternatif untuk digunakan sebagai pengubahsuai untuk tujuan meningkatkan ciri-ciri yang lebih baik kepada asfalt campuran panas. Kajian ini telah menggunakan serbuk getah dalam campuran asfalt panas (HMA) sebagai bahan tambahan. Serbuk getah telah dikenal pasti mempunyai potensi untuk menjadi bahan tambah di dalam campuran asfalt panas disebabkan sifatnya yang elastik dan sesuai bagi mengurangkan potensi berlakunya aluran pada permukaan jalan. Penggunaan serbuk getah di dalam kajian ini adalah untuk menggantikan agregat halus dengan peratusan sebanyak 1%, 2% dan 3% serbuk getah daripada berat agregat yang digunakan. Saiz serbuk getah yang digunakan di dalam kajian ini ialah 0.3 mm, dengan tiga perbezaan peratus kandungan bitumen (4%, 5% dan 6%). Proses yang digunakan dalam kajian ini adalah "proses kering" yang merujuk kepada campuran serbuk getah dengan agregat sebelum dicampurkannya di dalam bahan pengikat. Ujian Stabiliti untuk asfalt campuran telah digunakan dalam kajian ini. Semua spesimen telah disediakan untuk tujuan pengujian ciri- ciri Marshall iaitu untuk menentukan aliran, kestabilan, ketumpatan pukal, lompong udara dan lompang mineral di dalam agregat. Berdasarkan kepada keputusan yang diperolehi, penggantian serbuk getah mengikut peratusan sebagai agregat halus akan memberi kesan kepada prestasi asphalt campuran panas dengan ketara. Dengan menggantikan 1% serbuk getah, ia telah dikenalpasti bahawa peratusan serbuk getah ini adalah cukup baik untuk dipilih sebagai optimum dalam penggantian serbuk getah sebagai agregat halus dalam campuran asfalt.panas Melalui kajian ini juga, kesan dengan menggantikan serbuk getah sebagai agregat halus ke arah lompang udara telah dikenalpasti. Dapat disimpulkan bahawa dengan peningkatan peratus serbuk getah, lompang udara juga cenderung untuk meningkat. Keputusan yang diperolehi menunjukkan penggantian 1% serbuk getah boleh diterima berdasarkan spesifikasi JKR.

ABSTRACT

A lot of research has been conducted in finding other alternatives material in other to be used as modifier in asphalt mixes for the purpose of improving its characteristics. This research has been used crumb rubber in hot mix asphalt (HMA) as additive. Crumb rubber was identified to have a potential to becoming a modifier in HMA mixes due to the elastic behaviour exposed by the rubber particles especially in reducing rutting potential. The used of crumb rubber in this research is to replace fine aggregate by a percentage which is 1%, 2% and 3% of crumb rubber with the weight of aggregate. The size of crumb rubbers used in this research is 0.3 mm, with three difference percent of bitumen content (4%, 5% and 6%). The process used in this study is “dry process” which refers to the mix of crumb rubber with the aggregate prior to mixing it into the asphalt binder. The Marshall Stability Test method for asphalt mixture specimens was used in this research. All the specimens were prepared for evaluation of Marshall Properties which is to determine the flow, stability, bulk density, air void percentage and void in mineral aggregate. Based on the result, replaced the fine aggregate with crumb rubbers with percentage will affect the performance of Hot Mix Asphalt mixes (HMA mixes) significantly. By replacing with 1% of crumb rubber, it was identified that this percentage of crumb rubber is good enough to be chosen as the optimum for the crumb rubber replacement as fine aggregates in hot mix asphalt. Through this study also, the effect by replacing of crumb rubber as fine aggregate towards the air void had been found out. It can be concluded that with the increasing of crumb rubber percent, the air void also tends to increase. The result shown the percentage of crumb rubbers can be accepted regarding to the JKR Specification when replaced 1% of crumb rubbers.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

kN	**Kilo Newton**
mm	**Millimetre**
g	**Gram**
rpm	**Revolutions per minute**
cm	**Centimetre**
°C	**Degree Celsius**
%	**Percent**

LIST OF ABBREVIATIONS

HMA	**Hot Mix Asphalt**
CRM	**Crumb Rubber Modifier**
OAC	**Optimum Asphalt Content**
VFA	**Void Filled Asphalt**
JKR	**Jabatan Kerja Raya**
PWD	**Public Work Department**
RUMAC	**Rubberized Mix Asphalt Concrete**

CHAPTER 1

INTRODUCTION

1.1 Background

Many of research have been conducted to improving the quality of conventional asphalt. Recently, crumb rubber start to get more attention among the researchers as the modifier in order to improve the properties because of its promising a better performance in hot mix asphalt. Even though crumb rubber is one of the waste material, but it has potential to modify the conventional asphalt and overcome the structural damage in a form of rutting due to traffic loads. In Malaysia, the use of crumb rubber in pavement has been constructing but it's still under observation compared to the other countries such as Europe and United State. In fact, at United State the recycling crumb rubber has been used as modifier since 40 years ago (Lo Presti, 2013).

Thus, to use the crumb rubber as a modifying agent in hot mix asphalt in Malaysia, the detail research needs to conduct. A details research need to conduct regarding to the using of crumb rubber as a modifier in terms of performance of hot mix asphalt according to Malaysia's climatic condition. Therefore, the crumb rubber has been used to replace the fine aggregate in hot mix asphalt in this study to get a better performance. The properties of crumb rubber as fine aggregate in hot mix asphalt are expected to be determined throughout the test. Hence, crumb rubber could be a competent material in hot mix asphalt to improve the quality of road pavement compare to conventional pavement.

1.2 Problem statement

Nowadays, pavement problem is not a new issue to the highway engineers even though the pavement design life should be consider up to 10 years. The road damage becomes a critical due to some distresses like fatigue failure happen causes of the repeated traffic movement occurs by the wheel track. In addition, the climatic condition also one of the factors that contributed on pavement damage because the climatic condition in Malaysia is hot and wet over the year. In general, road pavement distresses are related to asphalt binder (bitumen) and asphalt mixture properties. Rutting and fatigue cracking are among the major distresses that lead to permanent failure of the pavement surface (Mashaan *et al.*, 2014). In order to improve the pavement problem, crumb rubber has been studying a few decades as a modifier in pavement mixes. Crumb rubber or waste tire is expected to overcome the pavement problem and it's also helping to reduce the environmental pollution by recycling the dumpling tires at the landfill (Abdul Hassan, 2007).

The other concern is about the cost effectiveness of using the crumb rubber in pavement mixture. The cost of using crumb rubber in pavement mixture is still under observation, but the early cost has been expected increases 15 percent compared to conventional pavement. However, the cost can be economical because of the pavement life can be increased due to the use of crumb rubber (Ali, 2015). The effectiveness of using crumb rubber not only occurs in Malaysia but it's also happens at developed countries such as United State because of lack of data regarding this crumb rubber in pavement mixture. Although many countries do a research about the usage of crumb rubber in hot mix asphalt, but the result is still difference. The difference result might be because of the difference devices used, climatic condition and size of the experimental conducted. Hence, the detailed study needs to be conducted to evaluate the performance of crumb rubber as a modifier in hot mix asphalt (Abdul Hassan, 2007).

1.3 Objective of Study

The main objectives in this study are to evaluate the performance of crumb rubber as fine aggregate in asphalt mixture. The focus of this study is on the following:

i. To determine the air void content in fine rubber particle in difference percentage.

ii. To evaluate the optimum fine rubber particle by replacing fine aggregate in hot mix asphalt in percentage.

1.4 Scope of Study

This study focuses on performance of crumb rubber as a modifier in hot mix asphalt. On this study each sample of hot mix asphalt was prepared based on Public Work Department (PWD) specifications using Marshall Design procedures after passing the entire characteristics test. The samples prepared were divided into 4 categories that is 0 to 3 percent of the weight of aggregate, so the numbers of samples are 36. All the samples must consists the per cent of crumb rubber as fine aggregates except the unmodified samples which is 0 per cent in order to find the suitable mixes that meet the better performance.

Crumb rubber was replaced the fine aggregate in a certain percentage in mixes by using Dry Process method according to the crumb rubber size, which is 0.3 mm. A dry process method where the rubber was replaced as part of the aggregate before it was blended with the asphalt. Even though the use of crumb rubber in this mixture was not going to replace all the aggregate, but it's still improving the performance of the mixes. To evaluate the improvements of crumb rubber performance as additive in hot mix asphalt the laboratory test was performed on the mix design.

1.5 Importance of Study

This study is important to improve the pavement damage due to traffic loads and study also helps to manage the issues of environmental pollution among waste tire. According to the study, the result of properties can be obtained from the Marshall Stability Test. The Marshall Stability test should be conducted to know the best properties between the control samples and modify crumb rubber samples to get a better performance. Thus, if the addition of crumb rubber can affect the properties of hot mix asphalt, the optimum content of crumb rubber can improve the performance of hot mix asphalt was determined.

1.6 Limitation of Study

This study covers on the topic of modified hot mix asphalt (HMA) with crumb rubber using dry process. For this study the crumb rubber will be used to replace the fine aggregate in HMA mixes. The size of crumb rubber is 0.3 mm and for the samples only cover dense graded (AC14) because there are commonly used for pavement design. However, the other category an example gap graded (SMA14) mixes could be suggested to use for further studies in the future.

For the samples preparation, all the procedures of Marshall Mix Design have been used according to the ASTM or BS. ASTM D1559 for Marshall Stability Test was used to test all the samples.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The government spent a lot of money on construction and maintenance roadways annually. So to reduce the cost for construction and maintenance roadways, it would greatly benefit to the government if the pavement life can be extended. Thus, this research has been conducted in order to enhance pavement performance regarding of the materials involved in pavement construction. At 1980s when people start to realize about the need to improve the conventional asphalt mixes and recycled tire crumb rubber become one of the alternative materials (Epps, 1994). Hence, Crumb rubber is one of the materials that could be an alternative to improve the pavement life.

2.2 Background of Crumb Rubber

Crumb rubber has been identified as the part of solid waste management problem nowadays. Every years many countries facing the same problem to manage the waste tires and it’s became one of the environmental issues. According to the available reports, annually, about one billion equivalent 9 million tons waste tires are produced in the world (G.H. Shafabakhsh, 2014). Due to the shortage of landfill space and environmental issues, recycling old tires seem necessary.

Figure 2.1 Waste Tires
Source: Abdul Hassan (2007)

Generally, Crumb rubber is a commodity made by re-processing (shredding) disposed automobile tires. Shredding waste tires and removing steel debris found in steel-belted tires generates crumb rubber (Issa & Salem, 2013). The scrap tires consist of rubber, carbon black, steel, and so forth potentially to be very useful in various applications which have been evaluated effectively as a valuable resource. There are some different recycling strategies developed for waste tires. From engineering sides, crumb rubber has the potential to improve the performance of asphalt concrete pavements. The large-scale usage of crumb rubber from waste tyres in asphalt mixtures appears to be more feasible alternative in terms of engineering applications and environmental consideration (Cetin, 2013). Crumb rubber can be find in many types of sizes which is the small size is 0.2 mm and below. However, the normal size commonly used in pavement design is around 2.0mm to 0.5mm and in term of safety it can be clarified as a non-toxic and inert material (Abdul Hassan, 2007).

According to the previous research, crumb rubber can reduce the noise because of their micro-surfacing materials. So, the idea to explore and mix crumb rubber with the asphalt mixture came from this factor. Now, since crumb rubber is made in form of loose granules, it is practical to incorporate crumb rubber into asphalt concrete whether to function as rubber-filler, asphalt-rubber, or as an additive. Modified asphalt pavement containing high air porosity due to crumb rubber that take place in the mixture will certainly increase the sound absorption capability in comparison with conventional asphalt pavement (Abdul Hassan, 2007). Even though crumb rubber is a recycle materials, but it gives a beneficial to the engineering fields and also from crumb rubber usage the tire pollutant can be reduce. From safety aspect, crumb rubber can be categorised as non- toxic and inert material (Abdul Hassan, 2007).

2.3 Crumb Rubber for Civil Engineering Application

Rubber from worn vehicles tyres which is cars, buses, trucks and bicycles after being shredded into smaller pieces, can often be reused in civil engineering applications. There are two ways of producing rubberised asphalt mixtures. In the first method, the wet process which is rubber particles are mixed with bitumen at elevated temperature prior to mixing with the hot aggregates. And the second method is dry process where the rubber particles will replace a small portion of the mineral aggregate in the asphalt mix before the addition of the bitumen (Al Qadi *et al.*, 2016). There are three major advantages for utilizing crumb rubber in the manufacture of rubber which is:

i. Use as a filler for reducing cost.

ii. Acoustic barriers

iii. Road base

iv. Adding functionality or modifying properties of the end products.

Because of crumb rubber is inexpensive filler in this application, so it also has been chosen for civil engineering fields. Even though the initial cost for construct the pavement is expensive compare to the conventional but the cost can be cover back according to increasing of pavement life. The increasing of pavement life will reduce the cost for maintenance (Ali, 2015).

2.4 Crumb Rubber as Aggregate in Pavement

Aggregate resources are becoming more and scarcer, especially in urban areas where most heavily trafficked pavements are located. It takes so expensive when want make maintenance or repair the defect of the road. Therefore, when use the crumb rubber it will reduce cost for maintenance and it will re-used significant benefits. Rubber aggregates can be used as bitumen modifiers or as substitutes for natural aggregates. The usage of crumb rubber as aggregate in pavement design can help to improve asphalt pavement skid resistance and durability. Rubber in rubberised asphalt mixtures increases the elasticity of the mixture which is it can enhance the bonding between binder and aggregates, resulting in an increase in fatigue life and in the resistance to rutting, and it can lead to a reduction of the thermal and reflecting cracking of these mixtures (Oikonomou & Mavridou, 2009).

2.5 Mix Production

There are two types of mix production can be used to incorporate crumb rubber into hot mix asphalt which are wet process and dry process. The wet process has the advantage that the binder properties are better controlled, while the dry process is often easier for an asphalt manufacturer to use. This is because wet process requires asphalt plants with another binder storage tank that can handle more viscous modified binder than conventional asphalt(Abdul Hassan, 2007). In the wet process, the crumb rubber is added directly to the bitumen, and its properties are modified. It is then added to the mix as a modified (Xiao *et al.*, 2009). While the dry process in contrast to the wet process, which is does not require special equipment but it has been a far less popular method. Dry process is the process of blends crumb rubber with hot aggregate prior to mixing it with asphalt binder. This unpopularity is because of the increased costs of having to use special graded aggregate to incorporate there claimed tyre rubber, in addition to construction difficulties, poor reproducibility and premature failure of asphalt road surfacing (Oikonomou & Mavridou, 2009). The dry process is limited to HMA applications whereas the wet process has been applied to crack sealants, surface treatments, and HMA mixtures. Figure 2.2 and 2.3 below has shown the dry and wet process method.

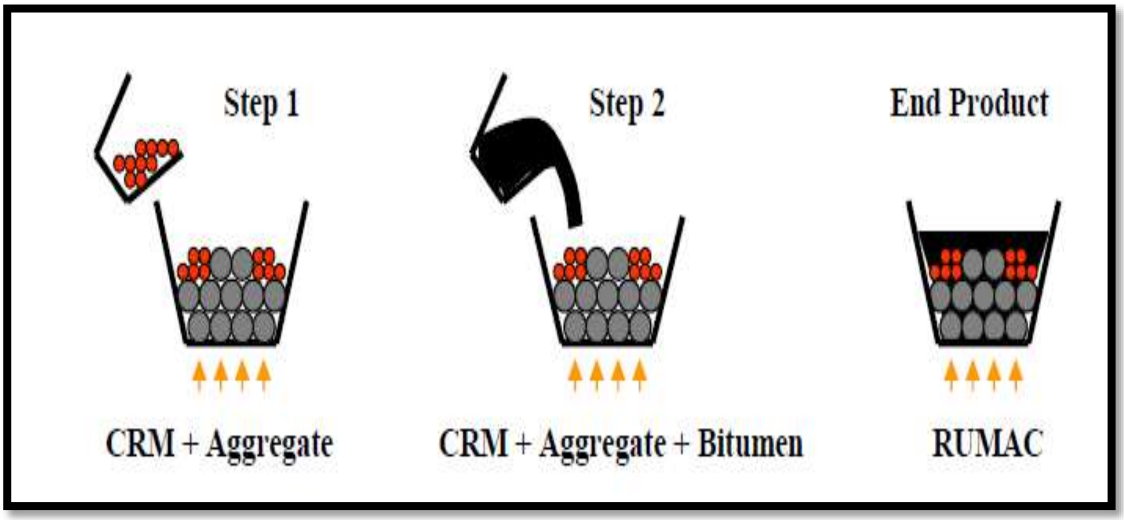

Figure 2.2 Dry Process

Source: Abdul Hassan (2007)

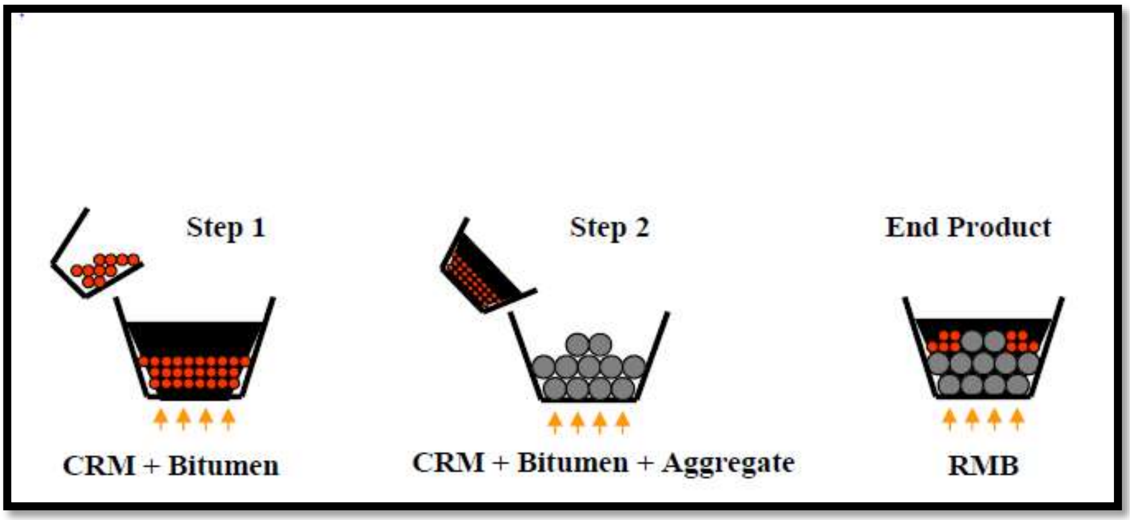

Figure 2.3 Wet Process

Source: Abdul Hassan (2007)

For the purpose of this study, dry process will be applied for mixing crumb rubber into aggregate with gap gradation and dense gradation. In this process fine aggregate will be replaced with crumb rubber by percentage from the total weight of fine aggregate. The percentage has been used is 1%, 2% and 3%.

2.6 Evaluating of CRM Mixes Performance

Based on this study the effect of replaced the crumb rubber by percentage as the fine aggregate can be evaluate. This study focuses on the performance of crumb rubber according to the characteristics of asphalt mixture which is to identify the stability, flow, air void and stiffness from the Marshall Stability Test. Pavements made of rubberised asphalt mixed with aggregates have been constructed widely with great success (Oikonomou & Mavridou, 2009). This rubberised asphalt can increases the services life of pavement compared to the conventional pavement. The idea of using the crumb rubber as a modifier in hot mix asphalt can be classified into two component systems which is crumb rubber modifier is assumed to reacts with the asphalt cement to produce a modified binder and another assumption is to replace a portion of the aggregate in hot mix asphalt and acts as an elastic aggregate. The modified crumb rubber mixes tested will be compared to the conventional asphalt concrete or unmodified sample (Abdul Hassan, 2007).

2.7 Summary

Crumb rubber has been study in several countries as the modifier in asphalt mixes to improve the pavement performance and simultaneously eliminating a waste product. Crumb rubber has been study as an additive in asphalt mixes. Rubber tyres, in different shapes and sizes can be used in civil engineering applications because of its properties. In this study, the method of dry process was used which is referring to a method that first blends crumb rubber with hot aggregates prior to mixing it with asphalt binder which the end product called Rubber Modified Asphalt Concrete (RUMAC) mixes (Elliot, 1993).

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, there are several tests has been discusses and were conducted at the Highway and Traffic Laboratory to achieve the objective of this study. All of the tests conducted have been referred to American Society for Testing and Materials (ASTM) and Public Work Department (PWD) specifications. The main materials in this study are aggregate and crumb rubber. Hence, to avoid any error regarding the tests the aggregates have been washed after the sieve analysis according to ASTM D422 were conducted. After that, the characteristic tests were conducted to identify the value of stability, flow, air void, VFA, bulk density and stiffness. In this study, crumb rubber with size of 0.3 mm which is in a powder form was used to replace the aggregate. The amount of crumb rubber has been replaced depending on the percentage which is 1%, 2% and 3% of the total weight of fine aggregate. Total of the samples was tested are 36.

3.2 Operational Framework

The operational framework for this study can be summarized as in the Figure 3.1 below:

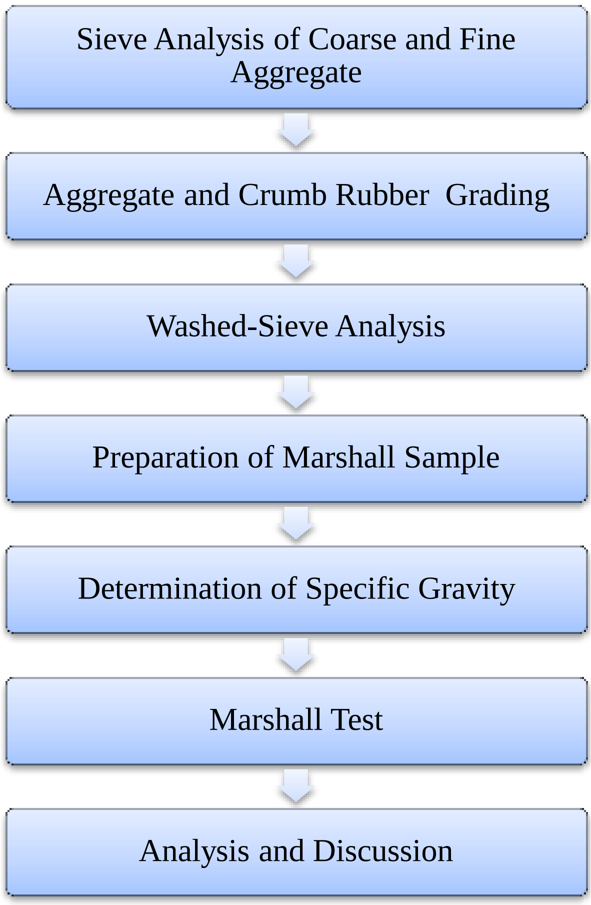

Figure 3.1 Flow Chart for Laboratory Process and Analysis

3.3 Sieve Analysis of Fine and Coarse Aggregate

Sieve analysis is the process of separating dry aggregates to determine the coarse and fine aggregates particle size. In this study, the size of sieves has standardized according to the ASTM D422.

3.3.1 Apparatus

i. Sieves – A set of sieves size 14mm, 10mm, 5mm, 3.35mm, 1.18mm, 0.425mm, 0.150mm, 0.075mm and pan.

ii. Mechanical sieve shaker - to expose the aggregates to all the openings in a sieve that will separate the dry aggregate from the bigger to smaller of particle size.

iii. Oven – An oven with appropriate size with the temperature of 110±5º was used to dry the aggregate after has been washed.

3.3.2 Procedures

i. The samples had been dried to constant weight at a temperature of 110±5º for 24 hours.

ii. The sieves with largest opening sizes are placed above the ones that having smaller opening sizes.

iii. The samples were placed inside on the sieve with the largest opening which located on the top of the rest of sieves.

iv. The sieves were stirred up by mechanical apparatus for a sufficient period which is 10-15minutes.

v. The specimen was washed and continued until the water coming through was cleared.

vi. Then the residue on each sieve was dried to constant weight at temperature 110±5º.

Figure 3.2 Mechanical Sieve Shaker

Figure 3.3 Washed Sieve Analysis

3.4 Aggregate Gradation

Aggregate gradation is the distribution of particle sizes expressed as a percentage of the total weight. Gradation is determined by sieve analysis, sieves are stacked from the largest openings on the top to the smallest opening on the bottom, and a pan is placed at the bottom of the stack, by passing the material through a series of sieves and weighing the material retained on each sieve, gradation can be determined.

The gradation of an aggregate is important to determine the percentages of aggregates for every size according to JKR/SPJ/rev/2005. Then the mass retained were calculated using the per cent passing for every sample size. Table 3.1 below show the weight of the aggregate used for AC14.

Table 3.1 Gradation limit for AC14

Size Sieve (mm)	**Passing by Weight (%)**	**Selected Gradation (%)**	**Percentage of weight of Aggregate (%)**	**Weight of Aggregate (g)**
14	90 – 100	95	5	56.9
10	76 – 86	81	14	159.32
5	50 – 62	56	25	284.5
3.35	40 – 54	47	9	102.42
1.18	18 – 34	26	21	238.98
0.425	12 – 24	18	8	91.04
0.15	6 – 14	10	8	91.04
0.075	4-Aug	6	4	45.52
Pan			6	68.28
Total				1138

Figure 3.4 Aggregates Gradation

3.5 Specific Gravity of Aggregate

Specific gravity can be defined as the ratio of the mass of a unit volume of aggregate, including the water permeable voids, at a stated temperature to the mass of an equal volume of gas-free distilled water at the stated temperature. Aggregate specific gravity is needed to determine weight-to-volume relationships and to calculate various volume-related quantities such as voids in mineral aggregate (VMA), and voids filled by asphalt (VFA). For this study the aggregate specific gravity has been used is 2.603.

3.6 LA Abrasion

The objective of the test is to obtain the Los Angeles number in the form of percentage wear of aggregates which reflects their resistance to degradation using the Los Angeles testing machine. All the test procedures below according to ASTM C131.

3.6.1 Apparatus

i. Los Angeles Abrasion Machine

ii. Metal tray

iii. Sieves sizes: 19 mm, 12.5 mm, 9.5 mm, 1.7 mm and pan

iv. Charges – these are steel spheres averaging approximately 46.8 mm in diameter and each weighing between 390 and 445 g

v. Sieve shaker

vi. Balance (accurate to 0.01 g)

3.6.2 Procedures

i. Samples are weight up to 2500g for every size; 14 – 12.5mm and 12.5 – 9.5mm.

ii. Samples are placed in Los Angeles Abrasion Machine.

iii. Eleven steel balls are added in the machine.

iv. The drum is rotated for about 500 revolutions at 30 – 33 rpm.

v. Sample is removed from the drum and sieved on no. 12 sieve after being rotated.

vi. The retained sample on the sieved is washed and dried at the temperature of 105 to 110ºC.After the sample cool down, weight of the sample are taken.

$$LA\ Abrasion\ Value\ (\%) = \frac{Weight\ loss\ (M_2)}{Initial\ weight\ (M_1)} \times 100 \quad (3.1)$$

3.7 Aggregate Impact Value

The objective of this experiment is to determine the aggregate impact value of road stone in the laboratory. All the test procedures below according to ASTM Designation and BS 812: Part 3.

3.7.1 Apparatus

i. Impact testing machine: It consists of a cylindrical hammer of 13.5 kg (30 lbs) sliding freely between two vertical supports (called guides). Its fall is automatically adjusted to a height of 38 cm. There is a brass plate over which an open cylindrical steel cup of internal diameter 10.2 cm and 5 cm depth is placed and fixed to the brass plate.

ii. Measure: A cylinder of internal diameter 7.5 cm and 5 cm deep for measuring aggregate.

iii. Tamping rod of 1 cm diameter and 23 cm long rounded at one end and pointed at the other end.

iv. Sieves: 12.5 mm, 10 mm and 2.36 mm openings

v. Balance: 5000 g capacity

vi. Laboratory oven capable of maintaining a constant temperature up to 110°C.

3.7.2 Procedures

i. Sieve the aggregate and obtain the portion passing 14 mm and retained on 10 mm sieve.

ii. Wash and dry this aggregate at a constant temperature of 105°C to 110°C; and then cool the sample. Weight the aggregate as M_1 (Initial Weight).

iii. Fill this aggregate in the cylindrical measure in 3 layers, tapping each layer 25 times with tamping rod. Level the surface tamping rod as a using the straight edge.

iv. Weight the aggregate in the measure. This weight of the aggregate is used for the duplicate test on the same materials.

v. Transfer the aggregate from the cylindrical measure to the cup in 3 layers and compact each layer by tamping in 25 strokes with tamping rod.

vi. Release the hammer to fall freely on the aggregate. The test sample is subjected to a total of 15 blows.

vii. Remove the aggregate sample from the cup and sieve through 2.36 mm sieve.

viii. Weight the fraction passing the sieve 2.36 mm as M_3 (Weight Loss).

$$\text{Aggregate Impact Value (\%)} = \frac{\text{Weight Loss } (M_3)}{\text{Initial Weight } (M_1)} \times 100 \quad (3.2)$$

Figure 3.5 Apparatus for Aggregate Impact Value

3.8 Aggregate Crushing Value

The objective of this experiment is to determine the mechanical strength of the aggregate. All the test procedures below according to BS 812: Part 3.

3.8.1 Apparatus

i. Open ended steel cylinder of nominal 150 mm diameter with plunger and base plate.

ii. A tamping rod with 16 mm diameter and 600 mm long.

iii. Balance of 3 kg minimum capacity.

iv. British Standard sieves of sieves 14 mm, 10 mm and 2.36 mm beaker.

v. Compression testing machine which is capable of applying force of 400 kN.

vi. Cylindrical metal measures for measuring the samples.

3.8.2 Procedures

i. Filled the aggregates in thirds into the cylinder where each third is subjected to 25 blows from the tamping rod. Weight the sample as M_1.

ii. The surface of the cylindrical is levelled and the plunger is inserted.

iii. Sample is placed between the platens of the testing machine and is located in a uniform rate so that the required 400 kN is reached in 10 minutes.

iv. Released the load and removed the crushed material.

v. Sieve through 2.36 mm sieves and weight the fraction passing the 2.36 mm as M_3.

$$\text{Aggregate Crushing Value (\%)} = \frac{\text{Weight Loss } (M_3)}{\text{Initial Weight } (M_1)} \times 100 \qquad (3.3)$$

Figure 3.6 Compression Machine

3.9 Ten Percent Fines

The objectives of this experiment are to identify the resistance of an aggregate crushing with corresponding to compressive load by calculating the force required to produce 10% fines. All the test procedures below according to BS 812: Part 3.

3.9.1 Apparatus

i. An opened ended steel cylinder with plunger and base plate.

ii. A tamping rod.

iii. A balance of 3 kg minimum capacity.

iv. British Standard 410 test sieves of sizes 14 mm, 10 mm and 2.36 mm.

v. A compression testing machine with the force applied varied from 5 kN to 500 kN.

vi. A cylindrical metal measured for measuring the sample.

3.9.2 Procedures

i. Sieve the aggregate and obtain the portion passing 14 mm and retained on 10 mm sieve.

ii. Filled the aggregates in thirds into cylinder and each third is subjected 25 blows of tamping rod released at 50 mm above the surface of the aggregate. Weight the aggregate (M_1).

iii. Level the surface of the aggregate and insert the plunger.

iv. Place the apparatus with the test sample between the platens of the testing machine and loaded in an uniform rate for 10 minutes to cause a penetration of;

v. 15 mm for rounded or partially rounded aggregates

vi. 20 mm for normal crushed aggregates

vii. 24 mm for honeycombed aggregated

viii. Record the maximum force applied to procedure the required penetration.

ix. Release the force and removed the crushed material in the cylinder into a tray.

x. Sieved the whole specimen in tray on the 2.36 mm sieve.

xi. Weight and record the fraction passing and retained on the sieve (M_3 plus M_2 respectively).

xii. If the total mass (M_3 plus M_2) differs from the initial mass M_1 by more than 10 g, discard the result and test further specimen.

To calculate

$$y\ (\%) = \textit{Weight Loss}\ (M_3)/\textit{Initial Weight}\ (M_1) \times 100 \qquad (3.4)$$

3.10 Bituminous Binder

In this study, bitumen grade 80/100 PEN according to the penetration test was used. The bitumen content was referring to the JKR/SPJ/rev/2005 and JKR/SPJ/1998. Table 3.2 below show the design bitumen content has been used.

Table 3.2 Design bitumen content

MIX TYPE	BITUMEN CONTENT
AC 14	4 - 6%

Figure 3.7 Bitumen Grade 80/100 PEN

3.11 Crumb Rubber Modifier (CRM)

Jing Yun Crumb Product Recycle Industries is the name of the factory that supplied crumb rubber for this study. With the reasonable price per kilogram and a lot of tyre waste it's not difficult to get it. For this study, the size has been chosen is 0.3 mm which is fine crumb rubber. The amount of crumb rubber modifier added into the mixes has been expressed in the percentages which are 0%, 1%, 2% and 3% of the total weight of aggregates per sample. The specific gravity of crumb rubber is approximately 1.15, and the product must be free of fabric, wire, or other contaminants (Heitzman, 1992).

Figure 3.8 Crumb Rubber

Table 3.3 The weight of the crumb rubber content by the weight of the fine aggregates.

Percentage of the Usage of the Crumb Rubber (%)	Crumb Rubber Content by Weight of the Fines Aggregates (g)	Weight of the Fine Aggregates (g)
0	0.0000	91.04000
1	0.9104	90.12696
2	1.8208	89.21920
3	2.7312	88.30880

3.12 Marshall Mix Design

Marshall Mix Design is the process to prepare standard specimens of asphalt concrete for the determination of stability and flow in the Marshall apparatus and also to determine density, percentage air void, and percentage of aggregate voids filled with binder.

3.12.1 Apparatus

i. Marshall Compactor

ii. Mixer

iii. Water Bath

iv. Marshall Compression Machine

v. Marshall Mould

vi. Sieve Shaker

vii. Oven

3.12.2 Procedures

i. The aggregate (about 1138.0 g), graded according to the ASTM or BS standard are over the dried at 170 – 180 ºC (not more than 280°C) for at least 4 hours.

ii. The required quantity of asphalt is weighed out and heated to a temperature of about 160 – 165 ºC for at least 4 hours. The thoroughly cleaned mould is heated in an oven to a temperature 140 – 170 ºC.

iii. A crater is formed in the aggregate, the binder poured in an mixing carried out until all the aggregate is coated. The mixing temperature shall be within the limit set for the binder temperature.

iv. A piece of filter paper is fitted in the bottom of the mould and the whole mix poured in three layers. The mix is then vigorously trowel15 times round the perimeter and 10 times in the center leaving a slightly rounded surface.

v. The mould is placed on the Marshall Compactor and given 50 blows.

vi. The specimen is then carefully removed from the mould then marked. Also the specimen is measured and weighed in the air, water and saturated surface dry (SSD).

3.12.2.1 Density and Void Analysis

1. Bulk density

By referred standard of ASTM D2726, bulk density can be tested. Bulk density is simply determined by weighing in air and water. Then:

$$Bulk\ Density,\ d = Gmb \times \rho w \qquad (3.5)$$

$$Gmb = [WD / (WSSD - WSUB)] \qquad (3.6)$$

Where:

d = Bulk density (g/cm³)

Gmb = Bulk Specific Gravity of the mix

ρw = Density of water (=1g/cm³)

WD = Mass of specimen in water (g)

WSSD = Mass of specimen in water (g)

WSUB = Surface dry mass (g)

2. Voids in Total Mix (VTM)

The percentage of air voids in the mix is determined by firstly calculating the theoretical density TMD (zero voids) and then expressing the difference between it and the actual bulk density; d, as a percentage of total volume.

$$VTM = [1-(d//TMD)] \times 100 \quad (3.7)$$

$$TMD = Gmm \times \rho w \quad (3.8)$$

$$Gmm = \{1/[((1-Pb)/Gse) + Pb/Gb]\} \quad (3.9)$$

Where:

d = Bulk density (g/cm³)

ρw = Density of water (=1g/cm³)

Gmm = Maximum theoretical Specific Gravity of the mix

TMD = Maximum theoretical density (g/cm³)

Pb = Asphalt content, percent by weight of the mix

Gse = Effective Specific Gravity of the mix

Gb = Specific Gravity of asphalt cement

3. Voids in the Mineral Aggregate (VMA)

The volume of void in mineral aggregate VMA is an important factor for the mixture design.

$$VMA = 100 \times \{1-[Gmb(1-Pb)/Gsb]\} \quad (3.10)$$

Where:

Gmb = Bulk Specific Gravity of the mix

Pb = Asphalt content, percent by weight of the mix

Gsb = Bulk Specific Gravity of the aggregate

4. Voids filled with Asphalt (VFA)

The VFA is the percentage of voids in the compacted aggregate mass that are filled with asphalt cement. It is synonymous with the asphalt-void ratio.

$$VFA = [(VMA-VTM)/VMA] \times 100 \qquad (3.11)$$

Figure 3.9 Weighted Out the Aggregate

Figure 3.10 Mixed the Asphalt and Aggregate

3.13 Marshall Stability Test

Marshall Stability Test is the process to measure the resistance to plastic flow of cylindrical specimens of an asphalt paving mixture loaded on the lateral surface dry means of the Marshall apparatus. This method is suitable for mixes containing aggregate up to 25mm maximum size. This design based on standard ASTM D1559.

3.13.1 Procedures

i. Three specimens, prepared according to the standard, are immersed in a water bath for 30 to 40 minutes or in an oven for 2 hours at 60±1.0ºC.

ii. The testing heads and guide rods are thoroughly cleaned, guide rods lubricated and heat maintained at temperature between 21.2 and 37.8ºC.

iii. A specimen is removed from the water bath or oven. Placed in the lower jaw and the upper jaw placed in the position. The complete assembly is then placed in the compression-testing machine and adjusted the flow meter to zero.

iv. The load is applied to the specimen at a constant strain rate of 50.8mm/min until the maximum load is reached. The maximum force and flow at that force are read and recorded. The maximum time that's allowed between removal of the specimens from the water bath and maximum load is 30 second.

Figure 3.11 Samples for Marshall Test

Figure 3.12 Marshall Stability Test Machine

3.14 Determination of Optimum Asphalt Content (OAC)

The principle of designing the optimum amount of binder content is to include sufficient amount of binder so that the aggregates are fully coated with bitumen and the voids within the bituminous material are sealed up. The mean optimum asphalt content were determined by plotting air void (VTM) equal to 4.0% by using method of US Department of Transportation's Procedure. Based on the optimum asphalt content, the average values of stability, bulk density, flow, stiffness and air voids can be obtained. Compare each of these values against specification values and if all are within specification, then the preceding optimum asphalt binder content is satisfactory. Otherwise, if any of these properties is outside the specification range the mixture should be redesigned.

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 crumb rubber replacement by percent are not same. In this study, the percent of crumb rubber has been used is 0%, 1%, 2% and 3% from the total weight of aggregates. The replacement of crumb rubber in this study as a fine aggregates. Hence, Marshall Stability Test has been conducted to get data for stability, flow, air void, VFA, stiffness and bulk density if the crumb rubber has been used as the additive in this study.

4.2 Aggregate Test

Aggregate plays an important role in pavement construction. Aggregates influence to a great extent and the load transfer capability of pavements. Hence it is essential that they should be thoroughly tested before using for construction. Not only that aggregates should be strong and durable, they should also possess proper shape and size to make the pavement act monolithically. Aggregates are tested for strength, toughness, hardness, shape, and water absorption.

In order to decide the suitability of the aggregate for use in pavement construction, following tests are carried out:

i. LA Abrasion Test

ii. Aggregate Impact Value

iii. Aggregate Crushing Value

iv. Ten Percent Fines

4.2.1 LA Abrasion Test

Table 4.1 LA abrasion value (%)

Aggregate size (mm)	Weight of Crushed Aggregate (g)			% Loss
	Before (m1)	After (m2)	Loss (m3)	
20 - 14	2500	3705.7	1282	25.6

The Los Angeles (L.A.) abrasion test is a common test method used to indicate aggregate toughness and abrasion characteristics. Aggregate abrasion characteristics are important because the constituent aggregate in HMA must resist crushing, degradation and disintegration in order to produce a high quality HMA. The standard L.A. abrasion test subjects a coarse aggregate sample that retained on 1.70 mm sieve to abrasion, impact, and grinding in a rotating steel drum containing a specified number of steel spheres (Anon., 2015). After being subjected to the rotating drum, the weight of aggregate that is retained on a 1.70 mm sieve is subtracted from the original weight to obtain a percentage of the total aggregate weight that has broken down and passed through the 1.70 mm sieve. The standard Los Angeles abrasion test is ASTM C 131. The table 4.1 above had shown the percentage of LA Abrasion loss.

4.2.2 Aggregate Impact Value

Table 4.2 Aggregate impact value (%)

Aggregate size (mm)	Weight of Crushed Aggregate (g)			% Loss
	Before (m1)	After (m2)	Loss (m3)	
14mm - 10 mm	290.5	222.2	84.7	29.1

Impact value of an aggregate is the percentage loss of weight particles passing 2.36mmsieve by the application of load by means of 15 blows of standard hammer and drop, under specified test condition. The aggregate impact value gives a relative measure of the resistance of an aggregate to sudden shock or impact, which in some aggregates differs from their resistance to a slowly applied compressive load. The table 4.2 above had shown the percentage of Aggregate impact value loss.

4.2.3 Aggregate Crushing Value

Table 4.3 Aggregate crushing value (%)

Aggregate size (mm)	**Weight of Crushed Aggregate (g)**			**% Loss**
	Before (m1)	**After (m2)**	**Loss (m3)**	
14mm - 10 mm	2530	1992.2	564.7	22.32

Aggregates used in road construction, should be strong enough to resist crushing under traffic wheel loads. If the aggregates are weak, stability of the pavement structure is likely to be adversely affected. The strength of coarse aggregates is assessed by aggregates crushing test. The aggregate crushing value provides a relative measure of resistance to crushing value provides a relative measure of resistance to crushing under a gradually applied compressive load. To achieve a high quality of pavement, aggregate possessing low aggregate crushing value should be preferred(IS:2386-part4, n.d.). Table 4.3 above had shown the percentage of Aggregate crushing value loss.

4.2.4 Ten Percent Fines

Table 4.4 Ten percent fines (%)

Aggregate size (mm)	**Weight of Crushed Aggregate (g)**			**% Loss**
	Before (m1)	**After (m2)**	**Loss (m3)**	
14mm - 10 mm	2498.6	2312.2	204.7	8.19

Ten percent fines value is a measure of the resistance of aggregate crushing subjected to loading and it is applicable to both weak and strong aggregate. Fine aggregates are defined as those passing 2.36 mm sieve. The test aims at looking for the forces required to produce 10% of fine values. This test is very similar to Aggregate Crushing Test in which a standard force 400kN is applied and fines material expressed as a percentage of the original mass is the aggregate crushing value (Anon., 2005). Table 4.3 above had shown the percentage of Ten percent fines loss.

4.3 MARSHALL SAMPLES

Marshall Samples was prepared based on ASTM D1559. All the equipment and procedures 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. 36 of samples were prepared to be tested by using Marshall Stability Test.

4.3.1 Preparation of samples

For the samples preparation there will be 0%, 1%, 2% and 3% of crumb rubber replacement as fine aggregates. The total weight of every sample is 1138.0 g excluded mould. Every sample has been poured and mixes with 4%, 5%, and 6% of bitumen grade 80/100 PEN. However, all the samples will be prepared and tested according to the specification as a guide to attain that the laboratory works and materials fulfil the Malaysian 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 4.5 Details of preparation process

Criteria	**Mix Type**	
	Conventional	**Modified**
CRM(%)	0	1 2 3
Asphalt Content (%)	4-6 (80/100 PEN)	
Curing Period	not applicable	
Marshall Compaction	75 blows/side	

4.4 MARSHALL TEST

From Marshall Test the result of stability, flow, stiffness, air void, VFA and bulk density was obtained. The result of conventional mixes and modified mixes was evaluated based on the quantity of crumb rubber replacement. The results of verified samples were recorded and shown in the Table 4.3, Table 4.4, Table 4.5 and Table 4.6 for conventional and modified mix design after added different percent of crumb rubber. However, all the modified asphalt needs to be check with (JKR/SPJ/2008) specification. Table 4.2 below shown all the parameters needed.

Table 4.6 JKR specifications

Parameter	**Requirement for wearing course based on JKR standard**
Stability, S	>8000 N
Flow, F	2.0mm -4.0mm
Stiffness, S	>2000N/mm
Air void in the mix	3.0% - 5.0%
Aggregate filled with bitumen/ VFA	70% - 80%

Table 4.7 Conventional mix

Bitumen (%)	**Corr. Stability (kN)**	**Flow (mm)**	**Bulk Density (g/cm³)**	**Air Void (%)**	**VFA (%)**	**Stiffness (Kg/mm)**
4	8.835	2.799	2.331	4.995	64.545	3.145
5	7.866	3.061	2.364	2.263	83.862	2.578
6	6.68	4.468	2.376	0.353	97.536	1.506

Table 4.8 1% of Crumb Rubber

Bitumen (%)	**Corr. Stability (kN)**	**Flow (mm)**	**Bulk Density (g/cm³)**	**Air Void (%)**	**VFA (%)**	**Stiffness (Kg/mm)**
4	16.513	3.829	2.344	4.461	68.606	4.155
5	21.165	4.598	2.352	2.757	80.588	4.551
6	12.349	5.772	2.374	0.467	96.77	2.13

Table 4.9 2% of Crumb Rubber

Bitumen (%)	**Corr. Stability (kN)**	**Flow (mm)**	**Bulk Density (g/cm³)**	**Air Void (%)**	**VFA (%)**	**Stiffness (Kg/mm)**
4	12.247	4.281	2.329	5.073	64.223	2.866
5	12.655	4.347	2.356	2.574	81.712	2.912
6	10.723	4.989	2.371	0.59	95.965	2.184

Table 4.10 3% of Crumb Rubber

Bitumen (%)	Corr. Stability (kN)	Flow (mm)	Bulk Density (g/cm^3)	Air Void (%)	VFA (%)	Stiffness (Kg/mm)
4	8.77	3.617	2.32	5.434	62.504	2.441
5	9.524	3.717	2.362	2.336	83.121	2.556
6	8.456	6.534	2.368	0.691	95.234	1.307

4.4.1 Air Voids –Binder Content Relationship

The air voids content of bituminous materials is an important control parameter for the quality of bitumen being laid and compacted. Air voids is a reverse proportion of the density of the compacted mix. By specifying a density requirement, the voids are inversely controlled. If the compacted mix has a high air void content, which is greater than 5% the mix will not perform as well under traffic. Similarly if the compacted mix has a low air-void content which is less than 3%, the mix will be susceptible to permanent deformation or rutting and also to distortion under the applied traffic loads. From the Figure 4.1 and Figure 4.2, the graph can be interpreted as the air voids will be decreases when the percentage of binder content increases. However, in terms of optimum asphalt content, the percentage of air voids is increases when the crumb rubber content increases. So, according to JKR/SPJ/2008 specification in Table 4.2, the data from Figure 4.6 which is 1% of crumb rubber, 2% of crumb rubber and 3% of crumb rubber with the air voids of 3.98%, 4.18% and 4.19% was passed the specification same as conventional mix which is 4.0%.

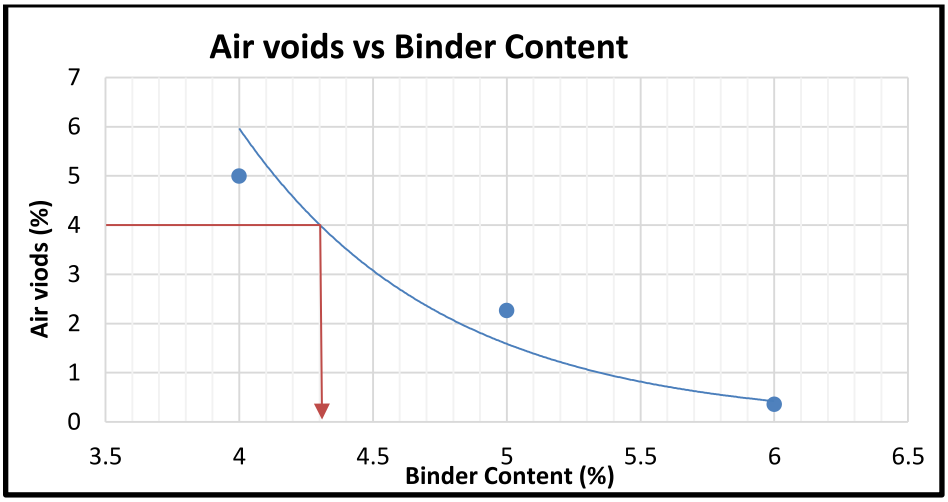

Figure 4.1 Air Voids vs Binder Content (Conventional)

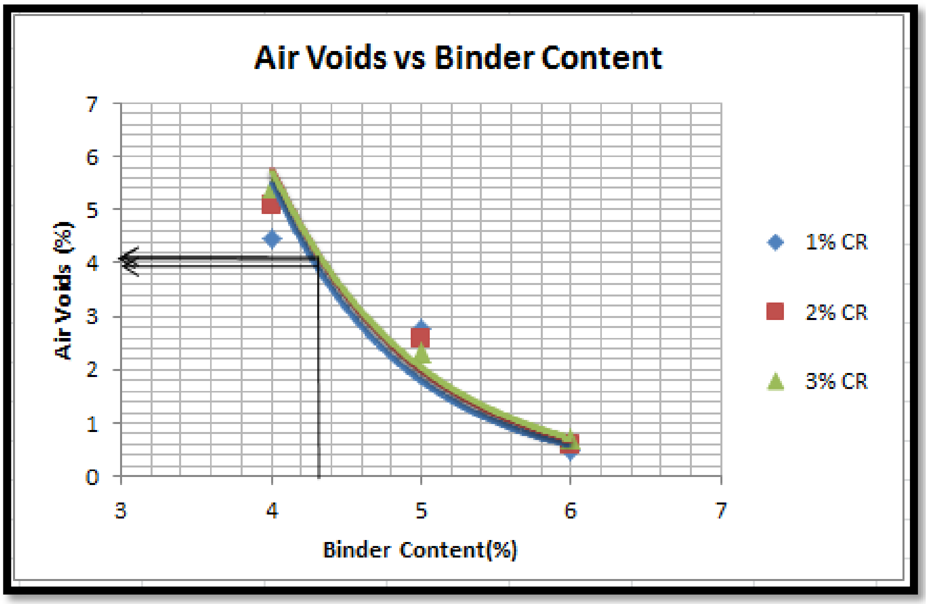

Figure 4.2 Air Voids vs Binder Content (Modified)

4.4.2 Stability–Binder Content Relationship

This test was done to find the Marshall stability of bituminous mixture as per ASTM D 1559. According to the Figure 4.3 and Figure 4.4 the result stability increases with increasing of asphalt binder content and it will decreases after it reaches a peak. However, based on the optimum binder content which is 4.3%, the stability will be decreases with the increasing of crumb rubber content. From the Figure 4.3 the value of stability is 8.0kN and for Figure 4.4 for 1% of crumb rubber, 2% of crumb rubber and 3% of crumb rubber the stability results are 18kN, 12.5kN and 8.9kN compared to conventional mix figure which is 8.7kN. So, by referring the JKR/SPJ/2008 specification in Table 4.6, all the modified passed this specification.

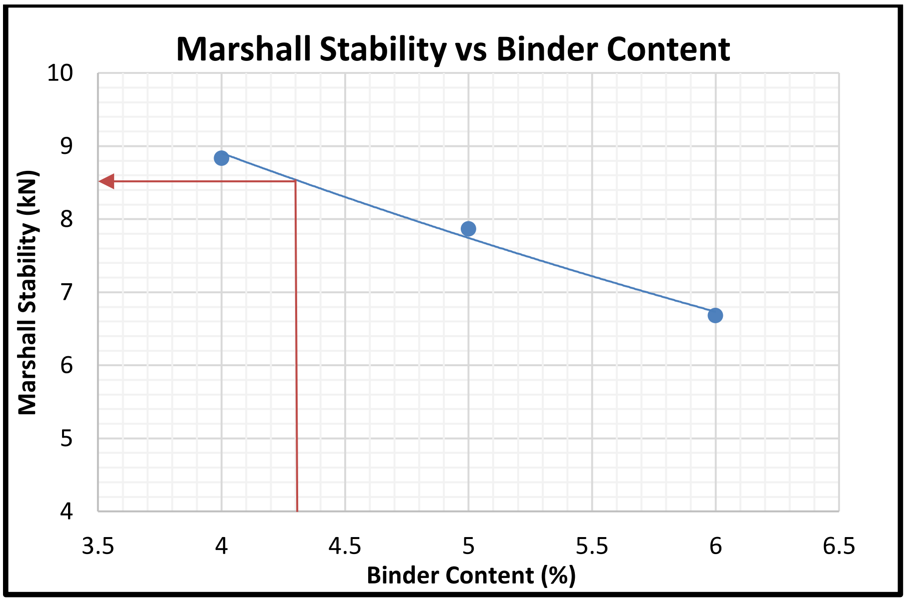

Figure 4.3 Marshall Stability vs Binder Content (Conventional)

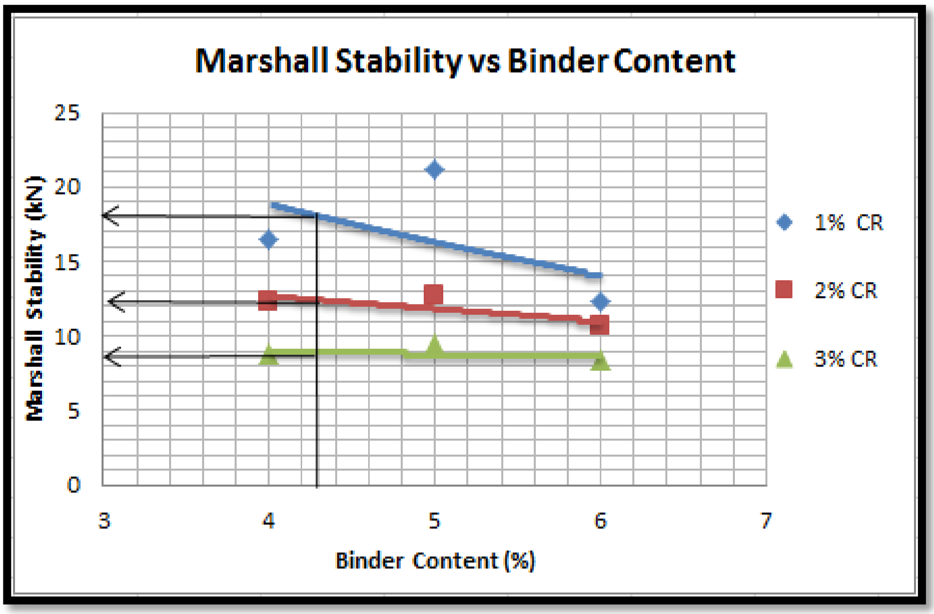

Figure 4.4: Stability vs Binder Content (Modified)

4.4.3 Bulk Density–Binder Content Relationship

The bulk density test is used to determine the specific gravity of a compacted HMA sample by determining the ratio of its weight to the weight of an equal volume of water. The bulk density is decisively one of hot mix asphalts characteristics because it is used to calculate other parameters, such as air voids, voids in mineral aggregates (VMA) and maximum density. From the optimum asphalt content which is 4.3%,

Figure 4.5 and Figure 4.6 shows the result that the bulk density will decreases with the increasing of crumb rubber content. Result for conventional mix the bulk density is 2.340 g/cm³ compared to 1% of crumb rubber, 2% of crumb rubber and 3% of crumb rubber, the results is 2.346 g/cm³, 2.338 g/cm³ and 2.332 g/cm³.

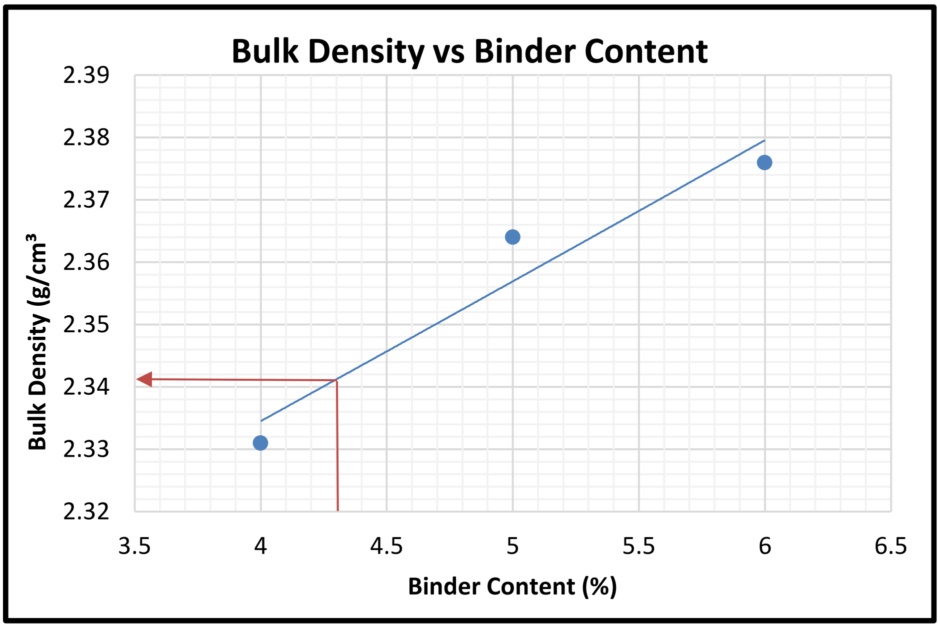

Figure 4.5 Bulk Density vs Binder Content (Conventional)

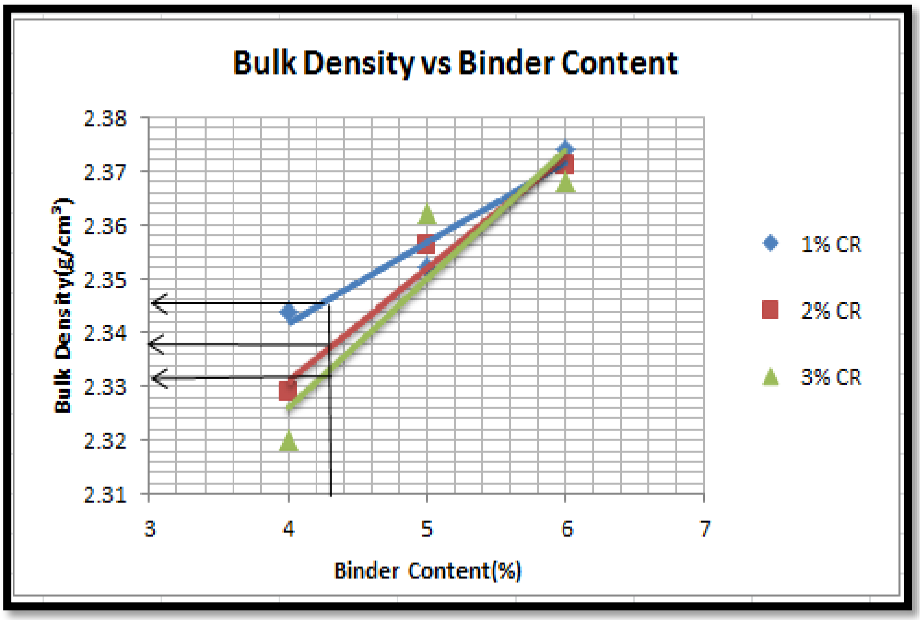

Figure 4.6 Bulk Density vs Binder Content (Modified)

4.4.4 Void Filled Asphalt (VFA) –Binder Content Relationship

The VFA is the percentage of voids in the compacted aggregate mass that are filled with asphalt binder. The VFA property is important not only as a measure of relative durability, but also because there is an excellent correlation between it and percent density. If the VFA is too low, there is not enough asphalt to provide durability and to over-densify under traffic and bleed. However, if VFA exceed approximately 80% and above, the dense mix typically becomes unstable and rutting is likely to occur. By refer the Figure 4.7 and Figure 4.8, the VFA for conventional mix is 70% and for 1% of crumb rubber, 2% of crumb rubber and 3% of crumb rubber the results are 71.8%, 68% and 66.5%. And according to the results from optimum asphalt content which is 4.3%, 2% of crumb rubber and 3% of crumb rubber didn't pass the JKR/SPJ/2008 specification in Table 4.6.

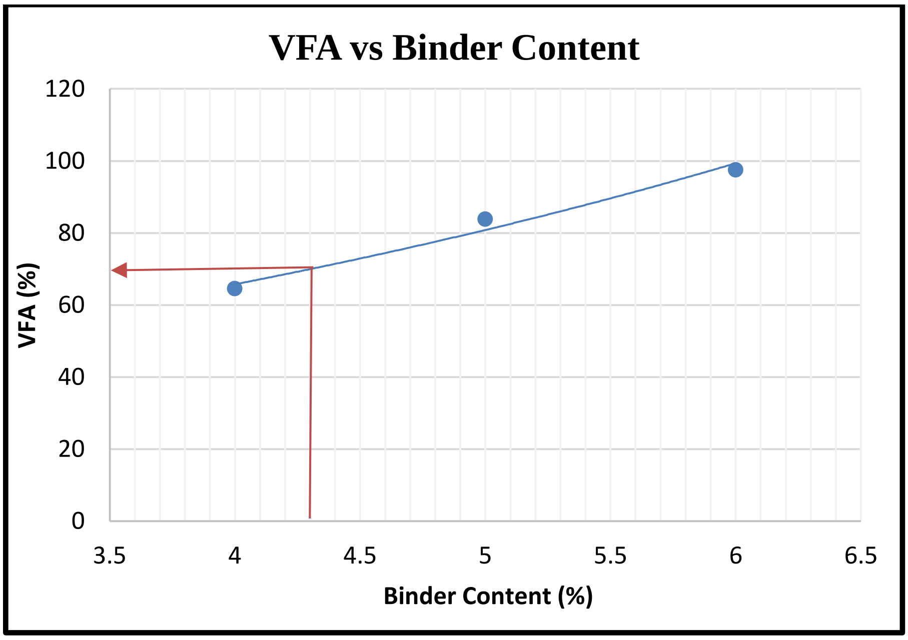

Figure 4.7 VFA vs Binder Content (Conventional)

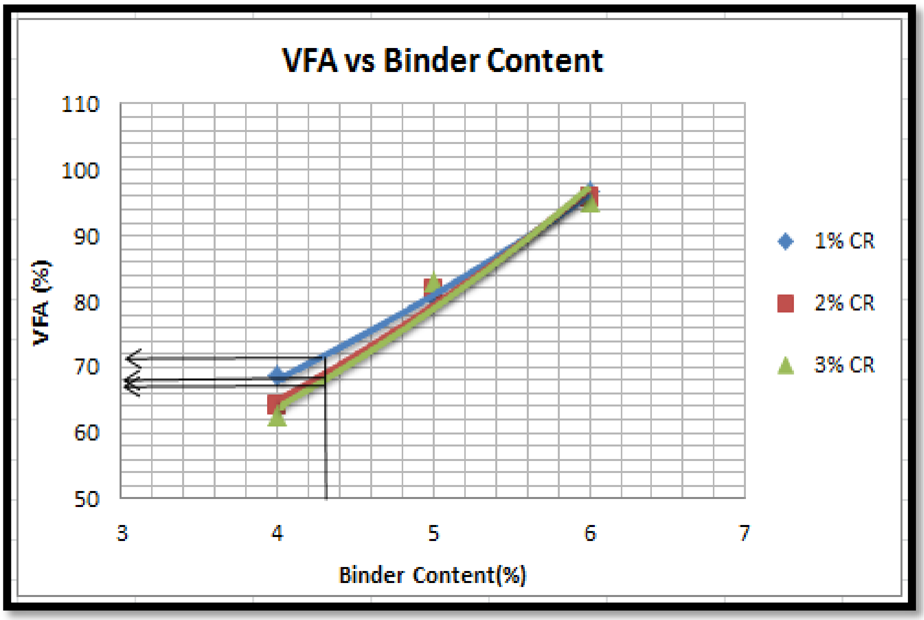

Figure 4.8 VFA vs Binder Content (Modified)

4.4.5 Flow–Binder Content Relationship

Figure 4.9 and 4.10 represented the results from conventional mix and modified mix. From the figure it shows that the flow will be increases with the increasing of binder content. According to the Table 4.6 which is summarized the JKR specification for flow, the result must be in 2.0 mm – 4.0 mm from the optimum asphalt content. However, only 1% of crumb rubber and 3% of crumb rubber pass the JKR/SPJ/2008 specification where the results value is 4.0 mm and 3.48 mm. 2% of crumb rubber didn't pass the specification of JKR because the value is 4.19 mm which is more than 4.0 mm. By refer to optimum asphalt content which is 4.3%, 2% of crumb rubber show the high value of flow and it may indicate an asphalt mixture that has plastic behaviour and has potential for permanent deformation, such as rutting or shoving, under loading.

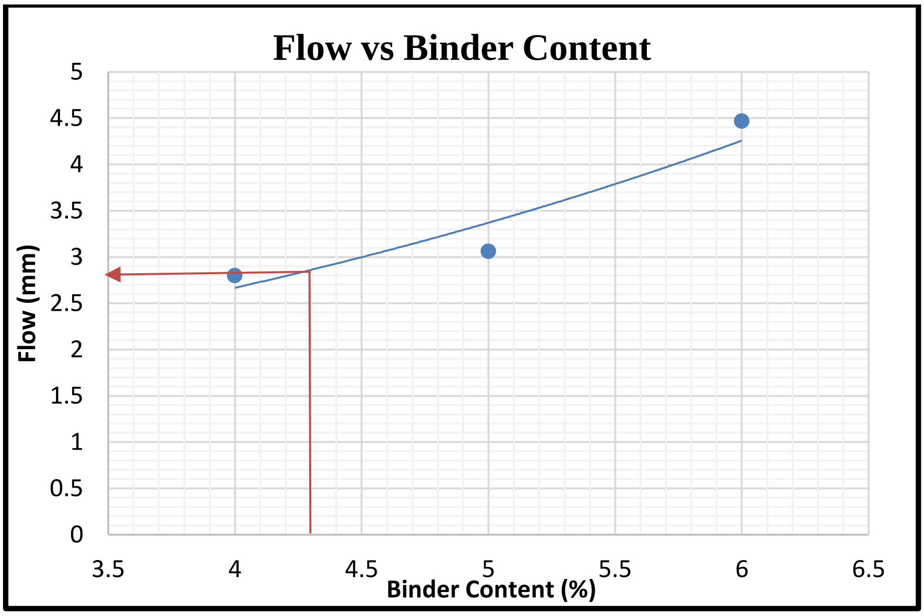

Figure 4.9 Flow vs Binder Content (Conventional)

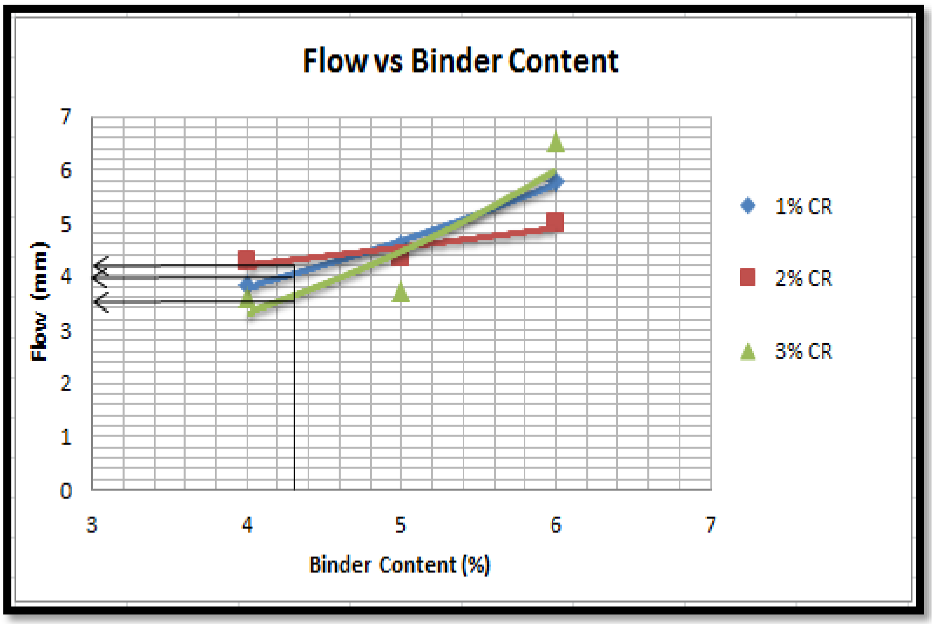

Figure 4.10 Flow vs Binder Content (Modified)

4.4.6 Stiffness–Binder Content Relationship

Stiffness modulus is considered to be a very important performance characteristic of the pavement. It is a measure of the load-spreading ability of the bituminous layers and controls the level of traffic induced tensile strains at the underside of the road base, which are responsible for fatigue cracking together with the compressive strains induced in the subgrade that can lead to permanent deformation (Kok et al., 2007). Figure 4.11 and Figure 4.12 represented the data for stiffness vs binder content. According to optimum asphalt content which is 4.3%, the value of 1% of crumb rubber, 2% of crumb rubber and 3% of crumb rubber where are 4.28, 2.82, and 2.48 already pass the JKR/SPJ/2008 specification in Table 4.6 same as conventional mix. Based on optimum asphalt content, the stiffness becomes decreases with the increasing of crumb rubber content. So, 1% of crumb rubber represented that the stiffer the mix, the less the rut depth.

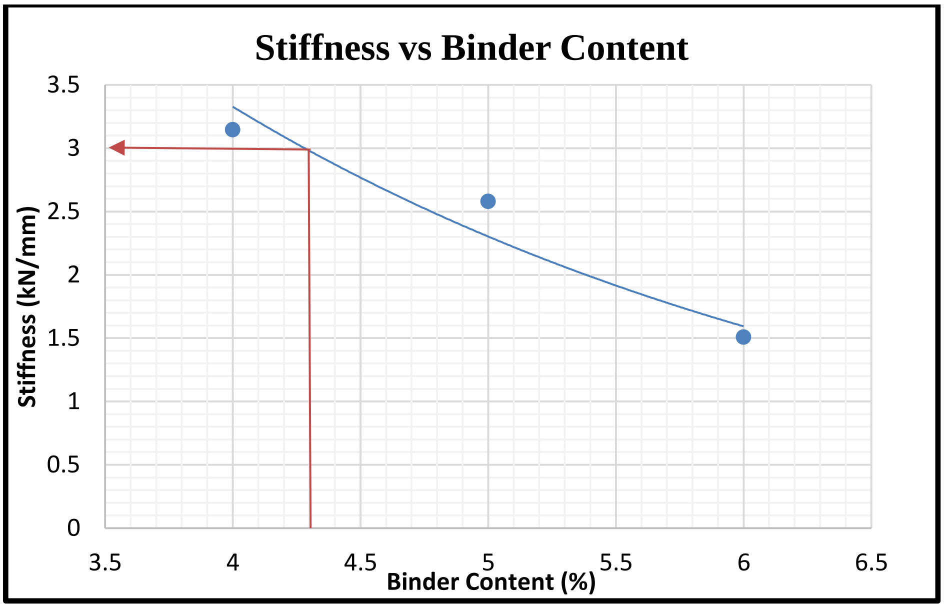

Figure 4.11 Stiffness vs Binder Content (Conventional)

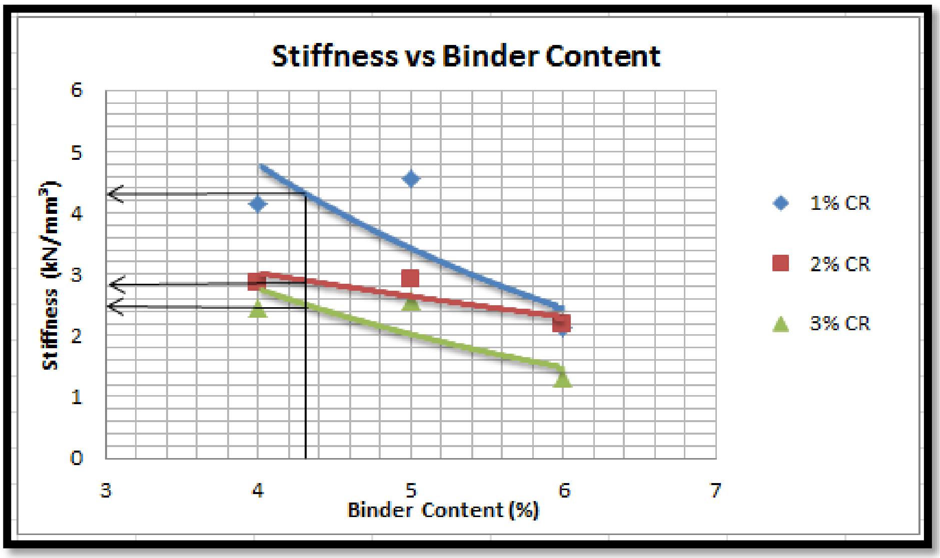

Figure 4.12 Stiffness vs Binder Content (Modified

CHAPTER 5

CONCLUSION

5.1 Conclusion

Based on this study, it was observed that the performance of HMA mixes was significantly affected with the addition of crumb rubber by using dry process. The Marshall Stability Test was conducted in this study to determine all the properties in HMA such as stability, air void, VFA, bulk density, flow and stiffness. According to the overall findings, the addition of 1% of crumb rubber was suggested in modifying the HMA mixes. By replacing with 1% of crumb rubber, it was identified that this percentage of crumb rubber is good enough to be chosen as the optimum for the crumb rubber replacement as fine aggregates in hot mix asphalt. In addition, through this study also, the effect by replacing of crumb rubber as fine aggregate towards the air void had been found out. It can be concluded that with the increasing of crumb rubber percent, the air void also tends to increase.

Hence, based on these findings, the objectives of the study has been achieved which is to determine the air void content in fine rubber particle in difference percentage and also to evaluate the optimum fine rubber particle by replacing fine aggregate in hot mix asphalt in percentage . All the overall findings referred to the JKR Specification which is (JKR/SPJ/2008).

5.2 RECOMMENDATION

For further studies in this topic, it was recommended to use a variety of crumb rubber types, sizes and percentages. Instead of dry process, wet process also can be carried out to know the differences results between the processes. In addition, the other test such as Indirect Tensile Test also can be conducted to studies the performance of crumb rubber as the fine aggregate in HMA. Lastly, the using of crumb rubber in Malaysia is still under research. So, further studies can be conducted to get the best percentages of crumb rubber as the modifier in HMA according to Malaysia condition.

REFERENCES

Abdul Hassan, N. (2007). Performance Of Hot Mix Asphalt Using Fine Crumb Rubber, (Crumb Rubber), 140.

Ali, M. Z. (2015). Jalan Berturap Getah Lebih Tahan Lama. Berita Harian. Retrieved from http://www.kkr.gov.my/public/Jalan berturap getah lebih tahan lama.pdf

American Society of Testing and Materials. Standard Test Method for Marshall Mix Design. ASTM D 1559. Civil Engineering Laboratory Manuals,2014.

British Standard. (1992). *Specification for aggregates from natural sources for concrete*. BS 882:1992.

Cetin, A. (2013). Effects of Crumb Rubber Size and Concentration on Performance of Porous Asphalt Mixtures. *International Journal of Polymer Science*.

Civil Engineering Portal. (2005). Retrieved from http://www.engineeringcivil.com/what-is-the-significance-of-ten-percent-fines-value-in-testing-sub-base-material.html

Elliott, R. P. (1993). Recycled Tire Rubber in Asphalt Mixes. Project Proposal submitted to the Arkansas State Highway and Transportation Department.

Epps, J. A. (1994). Uses of Recycled Rubber Tires in Highways- A Synthesis of Highway Practice. NCHRP Report No, 198.

G.H. Shafabakhsh, M. S. (2014). *Case study of rutting performance of HMA modified*, 69-75.

Heitzman, Michael, "Design and Construction of Asphalt Paving Materials with Crumb Rubber," Transportation Research Record No. 1339, Transportation Research Board, Washington, DC, 1992.

Issa, C. A., & Salem, G. (2013). Utilization of recycled crumb rubber as fine aggregates in concrete mix design. *Construction and Building Materials*, *42*, 48–52. https://doi.org/10.1016/j.conbuildmat.2012.12.054

JKR Malaysia. (2008). Standard Specification for Road Works, Section 4: Flexible Pavement, 1–187.

Kok, B. V., Kuloglu, N., Bağlayıcıların, F., Asfalt, S., Mekanik, K., & Etkisi, Ö. (2007). The Effects of Different Binders on Mechanical Properties of Hot Mix Asphalt. *International Journal of Science & Technology*, *2*(1), 41–48.

Lo Presti, D. (2013). Recycled Tyre Rubber Modified Bitumens for road asphalt mixtures: A literature review. *Construction and Building Materials*, *49*, 863–881. https://doi.org/10.1016/j.conbuildmat.2013.09.007

Norhayani Binti Mohd Nor, K. B. (2014). *Civil Engineering Laboratory Manual (2nd Edition).* Pahang: Universiti Malaysia Pahang.

Oikonomou, N., & Mavridou, S. (2009). The use of waste tyre rubber in civil engineering works. *Sustainability of Construction Materials*, *9*, 213–238. https://doi.org/10.1533/9781845695842.213

Salim Mashaan Nuha et al. (2014). A Review on Using Crumb Rubber in Reinforcement of Asphalt Pavement. Retrieved from http://www.hindawi.com/journals/tswj/2014/214612/#B2

Scribd. (n.d.). Retrieved from Scribd Web site: https://www.scribd.com/doc/86556617/Los-Angeles-Abrasion-Test

The Constructor Civil Engineering Home. (2015). Retrieved from Determination of Los Angeles Abrasion Value: https://theconstructor.org/building/building-material/determination-of-los-angeles-abrasion-value/1361/

Xiao, F., Amirkhanian, S. N., Shen, J., & Putman, B. (2009). Influences of crumb rubber size and type on reclaimed asphalt pavement (RAP) mixtures. *Construction and Building Materials*, *23*(2), 1028–1034. https://doi.org/10.1016/j.conbuildmat.2008.05.002

APPENDIX A
AGGREGATE TEST CALCULATION

LA ABRASION TEST

Aggregate size (mm)	Weight of Crushed Aggregate (g)			% Loss
	Before (m1)	After (m2)	Loss (m3)	
20 - 14	2500	3705.70	1282	25.60

LA Abrasion Value (%) = 1282 / 3705.70 x 100 = 25.60

AGGREGATE IMPACT VALUE

Aggregate size (mm)	Weight of Crushed Aggregate (g)			% Loss
	Before (m1)	After (m2)	Loss (m3)	
14mm - 10 mm	290.50	222.20	84.70	29.10

Agg. Crushing Value (%) = 87.40 / 290.50 x 100 = 29.10

AGGREGATE CRUSHING VALUE

Aggregate size (mm)	Weight of Crushed Aggregate (g)			% Loss
	Before (m1)	After (m2)	Loss (m3)	
14mm - 10 mm	2530.00	1992.20	564.70	22.32

Agg. Crushing Value (%) = 564.70 / 2530 x 100 =22.32

TEN PERCENT FINES

Aggregate size (mm)	Weight of Crushed Aggregate (g)			% Loss
	Before (m1)	After (m2)	Loss (m3)	
14mm - 10 mm	2498.60	2312.20	204.70	8.19

Agg. Crushing Value (%) = 204.70 / 2498.60 x 100 = 8.19

APPENDIX B
MARSHALL STABILITY TEST CALCULATION

Sample 1: diameter = 101.77mm

Average height = $\frac{65.23+64.94+64.84}{3}$

= 65.00mm

Volume of specimen = Average height x πr^2

= 65.00 x π x 50.885^2

= 528.74 x 10^3 mm^3

=528.74 cm^3

Determine the height correlation ratio from the table below:

Table A.1.1 Stability correlation ratio (from ASTM D1559)

Volume of specimen (cm^3)	Approximate thickness of specimen (mm)	Correlation ratio
200-213	25.4	5.56
214-225	27.0	5.00
226-237	28.6	4.55
238-250	30.2	4.17
251-264	31.8	3.85
265-276	33.3	3.57
277-289	34.9	3.33
290-301	36.5	3.03
302-316	38.1	2.78
317-328	39.7	2.50
329-340	41.3	2.27
341-353	42.9	2.08
354-367	44.4	1.92
368-379	46.0	1.79
380-392	47.6	1.67
393-405	49.2	1.56
406-420	50.8	1.47
421-431	52.4	1.39
432-443	54.0	1.32
444-456	55.6	1.25
457-470	57.2	1.19
471-482	58.7	1.14
483-495	60.3	1.09
496-508	61.9	1.04
509-522	63.5	1.00
523-535	65.1	0.96
536-546	66.7	0.93
547-559	68.3	0.89
560-573	69.8	0.86
574-585	71.4	0.83
586-598	73.0	0.81
599-610	74.6	0.78
611-625	76.2	0.76

Correction factor = 0.96

Marshall Stability = 17.331N

Corrected Marshall Stability = 17.331kN x 0.96

= 16.64 kN

Stiffness $= \frac{Marshall\ stability\ (kN)}{Flow\ (mm)}$

$= \frac{16.64}{4.416}$

= 3.768kN/mm

APPENDIX C
MARSHALL STABILITY TEST

I. Conventional Mix

Spec. No	Spec. Height (mm)	Weight in (g)			Bulk Vol. (cc)	Specific Gravity		Volume-%Total			Voids (%)			Stability Corr. Ratio	Stability (N)		Flow (mm)	Stiffness (Kg/mm)
		Air	Water	SSD		Bulk	Max. Theoretical	Bit.	Agg.	Voids	Agg.	Filled (Bit.	Total Mix		Div.	Corr.		
a	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t
					d-e	d/g	100/((b/Gac)+((100-b)/Gsb))	b*h/Gac	((100-b)*h)/Gsb	100 - j -k	100 - k	100*j/m	100-(100*h/i)			pqfpr		r/s
1	63.74	1180.4	674.2	1187.4	506.2	2.332	2.453	9.056	86.001	4.943	13.999	64.690	4.943	1	10.747	10.747	2.896	3.711
2	63.58	1179.9	677.3	1184.7	502.6	2.348	2.453	9.117	86.580	4.303	13.420	67.937	4.303	1	8.418	8.418	2.847	2.957
3	65.1	1175.6	667.2	1184.8	508.4	2.312	2.453	8.980	85.281	5.739	14.719	61.009	5.739	1	7.341	7.341	2.654	2.766
Avg						**2.331**					**14.046**	**64.545**	**4.995**			**8.835**	**2.799**	**3.145**
4	62.96	1176.8	683.6	1184.8	493.2	2.386	2.418	11.583	87.082	1.335	12.918	89.665	1.335	1.04	7.296	7.588	2.723	2.787
5	64.25	1189.1	679.4	1193.1	509.7	2.333	2.418	11.325	85.144	3.531	14.856	76.231	3.531	1	7.023	7.023	2.884	2.435
6	64.48	1201.1	694.7	1203.8	506.4	2.372	2.418	11.514	86.564	1.923	13.436	85.691	1.923	1	8.988	8.988	3.576	2.513
Avg						**2.364**					**13.737**	**83.862**	**2.263**			**7.866**	**3.061**	**2.578**
7	62.36	1196.7	693.7	1193.9	503	2.379	2.385	13.859	85.915	0.226	14.085	98.398	0.226	1.04	6.591	6.855	4.16	1.648
8	63.42	1184.8	684.6	1185.9	500.2	2.369	2.385	13.798	85.537	0.665	14.463	95.403	0.665	1	6.014	6.014	4.838	1.243
9	63.61	1199.3	695.5	1200.8	503.8	2.381	2.385	13.867	85.965	0.168	14.035	98.806	0.168	1	7.171	7.171	4.406	1.628
Avg						**2.376**					**14.194**	**97.536**	**0.353**			**6.680**	**4.468**	**1.506**

II. 1% CRM

Spec. No	% Bit.	Spec. Height (mm)	Weight in (g)			Bulk Vol. (cc)	Specific Gravity		Volume-%Total			Voids (%)			Stability Corr. Ratio	Stability (N)		Flow (mm)	Stiffness (Kg/mm)
			Air	Water	SSD		Bulk	Max. Theoretical	Bit.	Agg.	Voids	Agg.	Filled (Bit.	Total Mix		Div.	Corr.		
a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**	**j**	**k**	**l**	**m**	**n**	**o**	**p**	**q**	**r**	**s**	**t**
	% Bit. By weight of Mix					d-e	d/g	100/(b/Gac +((100-b)/Gsb))	b*h/Gac	(100-b)*h/Gsb	100-j-k	100 - k	100*j/m	100-(100*h/i)			pqfpr		r/s
1	4%	65.00	1183.30	676.60	1187.60	506.70	2.335	2.453	9.068	86.116	4.816	13.884	65.312	4.816	0.960	17.331	16.64	3.976	3.856
2		64.96	1185.80	681.70	1188.20	504.10	2.352	2.453	9.134	86.743	4.123	13.257	68.899	4.105	0.960	17.069	16.386	3.682	4.453
AVG							**2.344**	**2.453**	**9.101**	**86.430**	**4.470**	**13.571**	**68.606**	**4.461**		**17.200**	**16.513**	**3.829**	**4.155**
3	5%	65.15	1188.80	680.70	1191.70	508.10	2.340	2.418	11.359	85.401	3.240	14.599	77.807	3.226	0.960	19.279	18.509	5.108	3.610
4		63.58	1184.10	683.00	1185.70	501.10	2.363	2.418	11.471	86.241	2.288	13.759	83.369	2.288	1.000	23.820	23.82	4.087	5.705
AVG							**2.352**	**2.418**	**11.415**	**85.821**	**2.764**	**14.175**	**80.588**	**2.757**		**21.550**	**21.165**	**4.598**	**4.551**
5	6%	64.06	1208.50	699.20	1208.90	509.30	2.373	2.385	13.823	85.694	0.483	14.306	96.627	0.488	1.000	12.280	12.280	5.674	2.154
6		64.27	1206.40	698.20	1206.90	508.20	2.374	2.385	13.829	85.730	0.441	14.270	96.913	0.446	1.000	12.417	12.417	5.870	2.106
AVG							**2.374**	**2.385**	**13.826**	**85.712**	**0.462**	**14.288**	**96.770**	**0.467**		**12.349**	**12.349**	**5.772**	**2.130**

III. 2% CRM

Spec. No	% Bit.	Spec. Height (mm)	Weight in (g)			Bulk Vol. (cc)	Specific Gravity		Volume-%Total			Voids (%)			Stability Corr. Ratio	Stability (N)		Flow (mm)	Stiffness (Kg/mm)
			Air	Water	SSD		Bulk	Max. Theoretical	Bit.	Agg.	Voids	Agg.	Filled (Bit.	Total Mix		Div.	Corr.		
a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**	**j**	**k**	**l**	**m**	**n**	**o**	**p**	**q**	**r**	**s**	**t**
	% Bit. By weight of Mix					d-e	d/g	ac+((100-b)/Gsb))	b*h/Gac	(100-b)*h/Gsb	100 - j -k	100 - k	100*j/m	100-(100*h/i)			pqfpr		r/s
1	4%	64.24	1190.60	683.30	1193.20	507.30	2.347	2.453	9.114	86.556	4.330	13.444	67.796	4.330	1.000	11.381	11.381	4.364	2.608
2		67.02	1199.30	680.20	1208.70	519.10	2.310	2.453	8.972	85.207	5.821	14.793	60.651	5.816	0.930	14.100	13.113	4.198	3.124
AVG							**2.329**	**2.453**	**9.043**	**85.881**	**5.075**	**14.119**	**64.223**	**5.073**		**12.741**	**12.247**	**4.281**	**2.866**
3	5%	63.58	1199.00	692.50	1200.20	506.50	2.367	2.418	11.491	86.395	2.113	13.605	84.465	2.113	1.000	12.957	12.957	4.496	2.882
4		63.52	1188.20	681.50	1187.60	506.70	2.345	2.418	11.383	85.583	3.034	14.417	78.959	3.034	1.000	12.352	12.352	4.198	2.942
AVG							**2.356**	**2.418**	**11.437**	**85.989**	**2.574**	**14.011**	**81.712**	**2.574**		**12.655**	**12.655**	**4.347**	**2.912**
5	6%	63.41	1190.50	686.30	1191.50	504.20	2.361	2.385	13.754	85.267	0.309	14.733	93.357	0.979	1.040	12.352	12.846	4.684	2.743
6		62.05	1171.30	679.10	1171.80	492.20	2.380	2.385	13.862	85.937	0.201	14.063	98.574	0.201	1.040	8.269	8.600	5.293	1.625
AVG							**2.371**	**2.385**	**13.808**	**85.602**	**0.255**	14.398	**95.965**	**0.590**		**10.311**	**10.723**	**4.989**	**2.184**

IV. 3% CRM

Spec. No	% Bit.	Spec. Height (mm)	Weight in (g)			Bulk Vol. (cc)	Specific Gravity		Volume-%Total			Voids (%)			Stability Corr. Ratio	Stability (N)		Flow (mm)	Stiffness (Kg/mm)
			Air	Water	SSD		Bulk	Max. Theoretical	Bit.	Agg.	Voids	Agg.	Filled (Bit.	Total Mix		Div.	Corr.		
a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t
	% Bit. By weight of					d-e	d/g	100/(b/Gac+((100-	b*h/Gac	(100-b)*h/Gsb	100 - j -k	100 - k	100*j/m	100-(100*h/i)			pqfpr		r/s
1	4%	65.39	1169.20	661.40	1175.80	507.80	2.302	2.453	8.942	84.917	6.142	15.083	59.282	6.142	0.960	6.600	6.336	3.805	1.665
2		63.36	1176.70	673.20	1179.70	503.50	2.337	2.453	9.076	86.191	4.733	13.809	65.726	4.727	1.040	10.772	11.203	3.428	3.216
AVG							**2.320**	**2.453**	**9.009**	**85.554**	**5.437**	**14.446**	**62.504**	**5.434**		**8.686**	**8.770**	**3.617**	**2.441**
3	5%	62.87	1188.30	686.90	1189.20	501.40	2.370	2.418	11.505	86.495	2.000	13.505	85.189	2.000	1.040	10.175	10.582	4.016	2.635
4		63.28	1183.70	680.80	1184.90	502.90	2.354	2.418	11.426	85.903	2.671	14.097	81.054	2.671	1.000	8.465	8.465	3.418	2.477
AVG							**2.362**	**2.418**	**11.465**	**86.199**	**2.336**	**13.801**	**83.121**	**2.336**		**9.320**	**9.524**	**3.717**	**2.556**
5	6%	63.59	1202.70	692.60	1203.40	507.60	2.369	2.385	13.802	85.564	0.634	14.436	95.608	0.634	1.000	8.432	8.432	7.168	1.176
6		63.46	1203.70	695.10	1204.50	508.60	2.367	2.385	13.787	85.466	0.747	14.534	94.860	0.747	1.000	8.480	8.480	5.900	1.437
AVG							**2.368**	**2.385**	**13.794**	**85.515**	**0.691**	**14.485**	**95.234**	**0.691**		**8.456**	**8.456**	**6.534**	**1.307**

JKR Specification:

Parameter	Requirement for wearing course based on JKR standard
Stability, S	>8000 N
Flow, F	2.0mm -4.0mm
Stiffness, S	>2000N/mm
Air void in the mix	3.0% - 5.0%
Aggregate filled with bitumen/ VFA	70% - 80%

Details of Mix Produced:

Criteria	Mix Type			
	Conventional	Modified		
CRM(%)	0	1	2	3
Asphalt Content (%)	4-6 (80/100 PEN)			
Curing Period	not applicable			
Marshall Compaction	75 blows/side			