A STUDY ON THE STRENGTH OF CRUMB RUBBER MODIFIED BITUMEN USING VARIOUS CRUMB RUBBER SIZES

WAN MOHD FAKRI BIN WAN RAHIM

A thesis submitted in fulfilment of the

requirements for the award of the degree of

Bachelor of Civil Engineering (honour)

Faculty of Civil Engineering and Earth Resources

University Malaysia Pahang

JANUARY 2016

A STUDY ON THE STRENGTH OF CRUMB RUBBER MODIFIED BITUMEN USING VARIOUS CRUMB RUBBER SIZES

WAN MOHD FAKRI BIN WAN RAHIM

UNIVERSITI MALAYSIA PAHANG

UNIVERSITI MALAYSIA PAHANG

DECLARATION OF THESIS / UNDERGRADUATE PROJECT PAPER AND COPYRIGHT

Author's full name : **WAN MOHD FAKRI BIN WAN RAHIM**

Date of birth : **27 APRIL 1990**

Title : **A STUDY ON THE STRENGTH OF CRUMB RUBBER MODIFIED BITUMEN USING VARIOUS CRUMB RUBBER SIZES**

Academic Session : **2015/2016**

I declare that this thesis is classified as:

☐ **CONFIDENTIAL** (Contains confidential information under the Official Secret Act 1972)*

☐ **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 acknowledged that University Malaysia Pahang reserves the right as follows:

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

Certified by:

STUDENT SIGNATURE	**SIGNATURE OF SUPERVISOR**
Date: 15 JANUARY 2016	Date: 15 JANUARY 2016

NOTES: *If the thesis is CONFIDENTIAL or RESTRICTED, please attach with the letter from the organization with period and reasons for confidentiality or Restriction

I declare this thesis entitled **"A STUDY ON THE STRENGTH OF CRUMB RUBBER MODIFIED BITUMEN USING VARIOUS CRUMB RUBBER SIZES"** is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature ______________________________

Name of Candidate: Wan Mohd Fakri Bin Wan Rahim

Date : 15th January 2016

“To the Almighty God, my beloved parents and friends”

Thank You

ACKONOWLEDGEMENT

First and foremost, I would like to forward my hearties thanks to my supervisor, Madam Dr. Intan Suhana Binti Razelan for give a guide and encourage me throughout this thesis. Thanks a lot for giving me a professional training, advice and suggestion to bring this thesis to final form. Special thanks to the friends Mr. Arif Sulaiman, Mr. DzulHelmi Ariffin and Ab Rahim Che Ibrahim for always helped me to produce crumb rubber.

I am grateful to the staff of Faculty of Civil and Environmental Engineering of University Malaysia Pahang especially to those supportive lecturers. In preparing this thesis, I was in contact with many people, researches, academicians and practitioners. They have contributed towards my understanding and thoughts.

In particular, my sincere thankful is also extends to all my colleagues for giving hands in times of troubles. Not forgetting also to all the JP's for their great assistance at various occasions. Last but not least, thousands of thanks and gratitude to my parents and family for their never ending support and love.

ABSTRACT

Asphalt use in road pavement because it's very economical and fulfil the roadway design requirements such as good ride quality, ski –resistance surface, quiet surface and low maintenance. However, consumption of asphalt has some weakness, as it become brittle and hard in cold environments and soft in hot environments hence easy to crack. Besides that, today capacity or volume of the road user that increases year by year is one of the factors that make the road pavement prone to defect or damage such as cracking. Hard traffic and high loading weight also one of the factors affecting the quality of performance pavement and it becomes worst because of overloading on the road. Hence, to reduce damage and defect, an improvised road pavement structures is needed. This experiment will do modified in Asphalt with mix with different crumb rubber (2mm, 0.425mm, and 0.15mm) used as additives. The samples preparation consists of the production of the Marshall Mix specimens. Total of samples is 36 samples will prepare in the laboratory with proper method and apparatus. The samples is designed according to requirement for aggregate course wearing (ACW) using the JKR standard. The range percentage of asphalt was used in this study is 4% until 6%. The size of the sample is same to be prepared 1200 gram plus wastage. From the Marshall Stability and flow test the result is 19.522kN and 18.865kN for experimental samples and constants sample respectively. The conclusion, the crumb rubber can improve the workability, durability and provided higher density of the Hot Mix Asphalt. Furthermore, it gave the pavement a better performance and higher quality pavement for the future development. This finding also helps to save the budget to pavement for the future development. This finding also helps to save the budget to maintain the road in a good condition all the time being. Thus, it is an economical method to be applied in the road construction in order to increase the strength of pavement. In the future, hopefully this finding can encourage new research to be conducted in the different ways and usage.

ABSTRAK

Asfalt adalah salah satu bahan yang digunakan di dalam pembinan struktur jalan raya kerana ia sangat jimat dan memenuhi aspek jalan raya yang di perlukan seperti kualiti yang bagus, permukaan yang boleh mencengkam, tidak mengeluarkan bunyi dan penyelenggaraan yang murah. Walaubagaimanapun, penggunaan asphalt mempunyai sedikit kelemahan,dan salah satu kelemahannya adalah mudah untuk mengeras apabila cuaca sejuk dan lembut semasa cuaca panas dan mudah retak.Selain itu, kapasiti atau kuantiti pengguna jalan raya yang semakin bertambah setiap tahun ini akan menyebabkan permukaan struktur jalan raya terdedah kepada keretakan.Berat yang melebihi kesan dan trafik yang sentiasa melebihi kemampuan jalan juga adalah salah satu factor penyebab permukaan jalan raya selalu mempunyai masalah. Maka, untuk mengurangkan kerosakkan dan kesan penambahbaikkan perlu untuk menguatkan struktur permukaan jalan raya. Eksperimen ini akan melakukan penambahbaikkan kepada asfalt didalam permukaan jalan raya dengan memasukkan getah tayar yang dipotong dengan berbeza saiz getah tayar(2mm, 0.425mm dan 0.15mm). Jumlah 36 sampel akan dihasilkan di makmal dengan peralatan yang lebih cekap. Sampel akan dihasilkan mengikut spek JKR yang memerlukan mengikut kelas yang telah ditetapkan iaitu ACW. Peratusan julat yang digunakkan di dalam eksperimen ini adalah 4% hingga 6%.Berat sampel ialah 1200gram. Daripada Ujian stability yang dijalankan 19.522Kn DAN 18.865Kn untuk sampel ujikaji dan sample tetap mengikut urutan.Kesimpulannya, hirisan getah tayar boleh meningkatkan kebolehkerjaan, kecekapan , panjangkan jangka usia dan ketumpatan yang tinggi pada terapan tayar.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

	TITLE
CRM	**Crumb Rubber Modified**
HMA	**Hot Mix Asphalt**
VMA	**Voids Mix Aggregate**
VFA	**Void Filled Asphalt**
VTM	**Voids Total Mix**
ASTM	**American Society for Technology and Material**

CHAPTER 1

INTRODUCTION

1.1 Background Study

Binder is a general description for the glue used in asphalt pavements. These liquid binders can be call as tars or asphalt binder or bitumen. The terms “asphalt binder” has been selected to more specific describe the asphalt material and any modifiers or ingredients. The terms asphalt, asphalt cement, and asphalt binder referring more specifically to their petroleum origins and asphalt binder referring to the asphalt to the asphalt cement and any other added ingredient that provides the engineering adhesive used in asphalts pavements. Characteristic of asphalt is sticky, black and highly viscous liquid or semi-solid of petroleum. In pavement structures, asphalt is very importance in road because wearing coarse and base course need asphalt to mix in aggregate. Asphalt use in road pavement because it’s very economical and fulfill the roadway design requirements such as good ride quality, skid –resistance surface, quiet surface and low maintenance. However, consumption of the asphalt has some weaknesses, and of them is it become brittle and hard in cold environments and soft in hot environments hence easy to crack when the weather change from hot to cold. Moreover, today capacity or volume of the road user that increases year by year is one of the factors that make the road pavement prone to defect or damagesuch as cracking. Hard traffic and high loading weight also one of the factors affecting the quality of performance pavement as it becomes worst because of overloading on the road. Hence, to reduce damage and defect, an improvised is needed in the road pavement structures. In worldwide, it has many additives material such as Styrene Butadiene Styrene (SBS), Synthetic Rubber-Styrene-Butadiene (SBR), natural rubber, and Crumb Rubber Modified (CRM)to make it a strength the road pavement increased. The use of commercial polymers such as SBS and SBR is very expensive materials than crumb rubber very economical.

Crumb rubber very suitable to be the additives in pavement because it has the characteristic that can support the weakness of asphalt. Not only that, increase than that in tyres waste could be eliminated thus environmental problem can be avoided. The use of crumb rubber in asphalt materials became of interest to the paving industry because in the crumb rubber it has an elastic property which had the potential to improve the skid-resistance and durability of asphalt.The usage of crumb rubber is proving to be good and reliable. Besides that, crumb rubber can reduce the issue of fatigue or cracking occur on most pavement. At once, it can solve the damage and defect. Moreover, it can save the cost for the maintenance roadway pavement because ingredients in crumb rubber more benefits to solve the problem and also can solve environmental problem from waste tyres. Figure ~~2~~1show the pavement layer which is crumb rubber will include in binder course only. The thickness of the overall layer is similar with normal asphalt pavement using asphalt as binder. The constant layer is sub-base and sub-grade. The crumb rubber only in surface coarse and binder coarse because to avoid the pavement to crack on the surface or has a defect caused by heavy traffic loading.

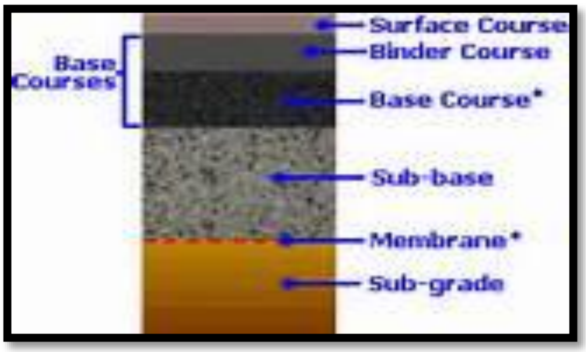


Figure 1: The Pavement Layer

Crumb rubber modified (CRM) is a rubber from waste tyres which is truck tyres, car tyres, motorcycle, bicycle or automotive tyres.The crumb rubber contains synthetic rubber, natural rubber, total rubber hydrocarbon and acetone extractable, which make a crumb rubber have high durability, viscosity, high softening point and better resilience.This due to the different portion of natural rubber synthetic rubber, and other components between truck tyres, passenger car tyres, and motorcycle tyre, bicycle tyres and others automotive tyres. A truck tyre has 80 per cent natural hydrocarbon and 18 per cent natural rubber compared 9 percent in an others automobile and 2 per cent in tyre treads. For truck tyres, it must separate between steel and fibres in tyres. Tyre rubber will be liquid nitrogen and is easily fractured in a hammer mill. While, ambienttemperature produces sponge-like crumb rubber with big surface area.

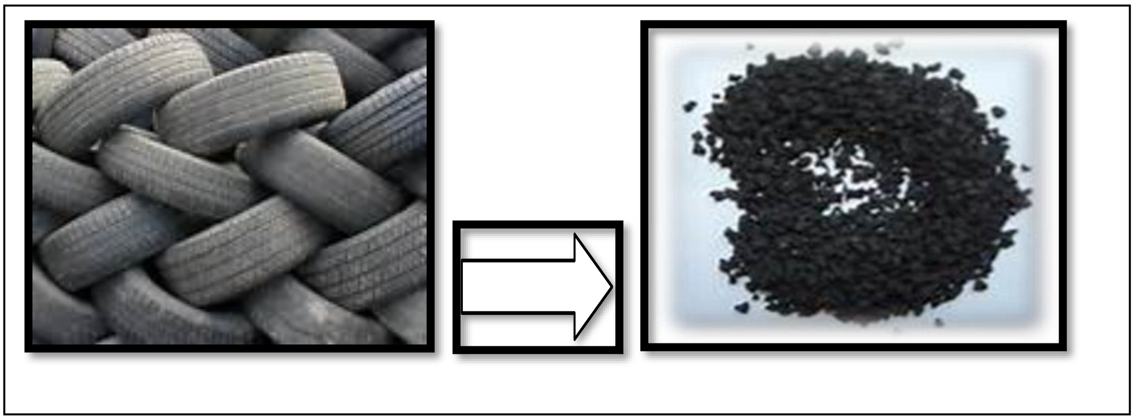


Figure 2: Transformation of the waste tyre to Crumb rubber

Figure 2 shows from the waste tyres become crumb rubber using ambient grinding process. This is one of the processes to produce crumb rubber. This mechanical process will produce an irregularly shaped particle with a large surface area and varies from size 0.425mm to 4.75mm. After, this processes, it will produce the shape or crumb rubber or the specifically known particle morphology such as Figure 2. The ambient grinding will produce rough irregular shape with high surface area. Crumb rubbers have five grading;

1) Tire granule shall consist of granule tire crumb, black only guaranteed, and metal, free sized. Magnetically separated materials are not acceptable. Fluff from tire cord removed.

2) Groups, tire granule consist of granulated tire crumb, black and white guaranteed metal free, sized 40mesh.

3) Tyre granule consists of crumb, black only magnetically separated.

4)Tire consist of granulated the crumb and the last, the granule consist of unclassified of granulated tire crumb, sized, and not separated.

Another process to produce crumb rubber is cryogenics process; it will produce the shape of crumb rubber look like an angular or prismatic shape and smooth surfaces. This process uses liquid nitrogen to freeze the recycle tyre rubber until it becomes brittle, and then uses a hammer mill to shatter the frozen rubber into smooth particles with lower surface area than those obtained ambient process.In addition,it has two another processes to produce crumb rubber.The processes are wet-grinding and hydro jet size. Wet-grinding will be produce from solid to liquid and Hydro jet size reduction one of the technique of processing rubber tyre recycle into finer particles with the help of pressure water.

1.2. Problem Statement

Over the years, the damagein roadway pavement in Malaysia iskept on increase. Lots of maintenance work need to be repaired to reduce defect or damage on the roadway. This is because of heavy traffic load or increasing road users in Malaysia. Statistic from Ministry Of Transport Malaysia, the road users increase from2009 to 2010 and is expected to keep on increasingfor the next 10 years.When the road user increase, the loading in the road will be increased and the pavement have a problem if the pavement cannot support the high loading or volume (Sulyman, 2014).

Moreover, asphalt cannot withstand drastic weatherchangesbecause asphaltishard 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.Besides that, asphalt also has a thickness problem, bleeding, flushing and drain-down.The roadway pavement in Malaysia is always has a defect which mainly because of excessive load and hightemperature. Therefore to overcome this problem, crumb rubber issuggested as oneof the methods that might be able to solve the environmental problem and roadway pavement. Crumb rubber will increase the strength and will give elastic in the roadway pavement.

Besides that, waste tyres are one of the environmental problems inMalaysia. 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. Recycledthe tyres will be the one of way to save the space. The global problem with landfill disposal of automobile tires and plastics can only be solved by the feasible option left, and that is recycling and utilization of the recycled products (Rokade, 2012). It is thought that the application of recycled automobile tires and plastics will not only solve the environmental of these industrial solid wastes problem but also act as very promising modifiers for the improvement of asphalt pavement material.

Therefore, the potential of crumb rubber as additive in asphalt pavement will be tested in this research.A crumb rubber will prevent the pavement to crack in the cold or melt in the heat. Itcanalso increases film thickness in the aggregate that can prevent bleeding, flushing and reduce noises. Crumb rubber also has higher durability than asphalt. So, crumb rubber will be used as additives in asphalt pavement. The concentration and size of crumb rubber will be balanced with asphalt.By using this method, the strength of pavement will be increased and the environmental rescue of wastage tyres could be reduced.

1.3 Objective of the Study

The main objective of this project is to investigate the strength of road pavement when crumb rubber isuse as additive in asphalt pavement.The specific objectives for the project are:

a) To investigate different sizes of crumb rubber that will influence the strength of road pavement.

b) To determine the strength of crumb rubber modified asphaltto be used as surface course.

1.4 Scope of Study

1. Laboratory testing such as Marshall Stability, compression, and balance and water bath test will be conducted to achieve the objectives.

2. The crumb rubber material wasobtained from the exhausted bicycle tyres.

3. The quantity of bicycle tyres and aggregates similar with typical asphalt pavement design.

4. The project consists of 30 samples of preparation. There are 15 will be control samples prepared in order to compare it with the samples mixed with the crumb rubber.

5. Finally, the strength of the samples was determined by using civil engineer laboratory manual UMP test according and the material standard is following the JKR Specifications 4.1.4.2and ASTM or BS standard.

1.5Significant of Study

This research is important to solve the problem of pavement strength and environmental problem which is come from waste tyres. Both issues will be solved by reuse the scrap tyres and produces crumb rubber before using it in the road construction by adding as sub base or surface coarse pavement layer. Furthermore, the used of crumb rubber in the road will reduce noises, prevent bleeding, flushing and drain down, increase the performance life, very economically and increase safety.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The first problem of the asphalt is itwills brittle in cold environments and soft in hot environment.In addition, when hard traffic and high loading weight will give the effect for pavement material such as cracking, fatigue cracking, and the rutting at high temperature, causing its quality and performance in pavement of roads to decrease(Al-maamori, 2014). This will make the roadway need maintenance year by year. The properties of asphalt-Aggregate mixed such as stiffness, stability, durability, fatigue, resistance, fracture, characteristics, skid Resistance,permeability,and workability majority depends on the content of asphalt. If contain asphalt only the pavement is not fully efficiently because asphalt have a limitation and it need additives. That caused range of rheological and durability properties the asphalt not sufficient for resistance on distresses caused by the increase traffic and total loading on current highway(Bahia, 2006).

Impact of heavy transport in pavement can be seen in different types of defects. Defects in flexible pavements can be placed into one of five classes. These classes are cracking, distortion, disintegration, slippery surfaces and surface treatment problems.For the cracking, it have alligator cracking, edge cracks, edge joint cracks, reflection cracks and lane joint cracks. Reflection cracks normally occur in asphalts overlays. These cracks reflect the cracks pattern in the pavement structure underneath. There are most frequently found in asphalt overlays over Portland concrete and cement-treated bases. Reflection cracks are normally caused by vertical or horizontal movements in the pavements beneath the overlays, resulting from traffic loads, temperature and earth movements. Therefore, as asphalt replacement or modifications need to be carried out to ensure that asphalt is strong enough yet economical to be used as road pavements.

2.2 Modification Asphalt

Asphalt modification is a process done to enhance the strength and life of pavement. Modifications can combined or put an additive to asphalt. Thermoplastic, polymers, thermo set, polymers, reinforce agents; adhesion, promoter, catalyst, chemical reaction, crumb rubber and aging inhibitors use in modified of asphalt, only to strength the road pavement and avoid the maintenance every year.Not all types of modifiers are being currently used.The frequency of user varies significantly depending on marketing of the modifiers, experience of contractors and agencies and cost(Bahia, 2006).The effect of mineral fillers, polymeric and crumb rubber additives on performance-related properties of asphalt cements have been analyzed using data collected for a normal binders.The analysis measured using new characterization technique developed by the Strategic Highway Research Program(SHRP).

For the polymeric additives, it contains styrene-butadiene (SB) based-modifiers and polyethylene-based modifiers.Theresult gets to reduce the sensitivity of rheological properties to temperature and loading frequency. Polymer, result is a higher stiffness and a lower phase angle. At intermediate and low temperatures, the effects are less pronounced and can be favourable(Bahia, 2006).While, mineral fillers result is similar in effects similar to the modifiers with respect to reduction in dependency of asphalt rheology on temperature and loading frequency.However, result shows an increased in stiffness at all temperatures and frequencies. The effect at high temperatures are favourable, their effects at intermediates and low temperatures are not favourable and can be determined with respect to fatigue and thermal cracking(Bahia, 2006).Therefore, it is necessary to improve the quality of asphalt by the material which can play the role as a binder to achieve increasing viscosity and elasticity, diminution of temperature higher softening point and aging resistance(Al-maamori, 2014).

Crumb rubber modifiers included ambient shredded crumb rubber, cryogenic grinded and a crumb rubber plastics composite. All crumb rubbers were produced from whole tire stock with maximum particle size of 5.0 mm and minimum size is 0.425mm. The result also is similar with effects to polymer modification. From the data, crumb rubber modifiersin reduction of stiffness at the intermediate and low temperatures if their stiffness is less than the stiffness of the asphalt matrix(Bahia, 2006).

Moreover, the crumb rubber modified (CRM) is the additives to avoid damage in the road pavement. Where,conventional bitumen Crumb Rubber Modified Bitumen (CRMB) is mostly used. Its advantages are:

1. Lower susceptibility to daily & seasonal temperature variations

2. Higher resistance to deformation at elevated pavement temperature

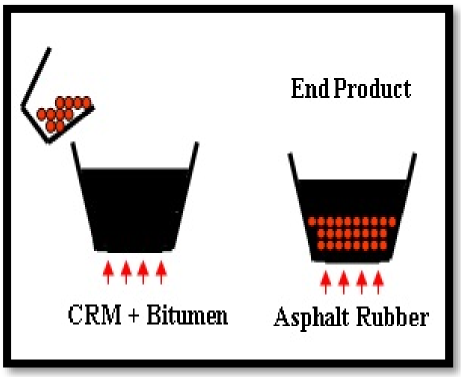
3. Better age resistance properties, higher fatigue life of mixes

4. Better adhesion between aggregate & binder

5. Prevention of cracking & reflective cracking

6.Overall improved performance in extreme climatic conditions & under heavy traffic condition(Nabin R. M., 2014).

It can also reduce noise emissions(Losa, 2003). Physical properties of rubber such as type, quantity, shape, gradation are said to affect the performance of rubber modified asphalt mixtures (Norhidayah Abdul Hassan et al, 2014). Therefore, this study attempt to determine suitable crumb rubber size that would affect the strength, durability, stiffness, stability, durability, fatigue resistance, fracture resistance, skid resistance, permeability and workability of the asphalt. To modify the asphalt pavement, it has two processeswhich are dry process and wet process. The dry process involves the blending of crumb rubber with hot aggregates prior to mixing with bitumen and substitutes a proportion of the mix aggregate with coarse rubber, thereby causing the rubber to function essentially as an elastic aggregate within the mixture while wet process is a whereby fine rubber is blended with hot bitumen to produce a 'rubberised bitumen' binder(Norhidayah Abdul Hassan et al, 2014).Although decades of research have been dedicated to the study of CRM mixtures, results produced have been largely inconsistent. The difference in wet mixing process and dry mixing process are illustrated in below Figure 2.1 and Figure 2.2.Figure 2.1 show the wet process method where rubber particles are mixed with asphalt at elevated temperature prior to mixing with the hot aggregates .Figure 2.2 show the dry process, where rubber particles replace a small portion of the mineral aggregate in asphalt mix before the addition of the asphalt.



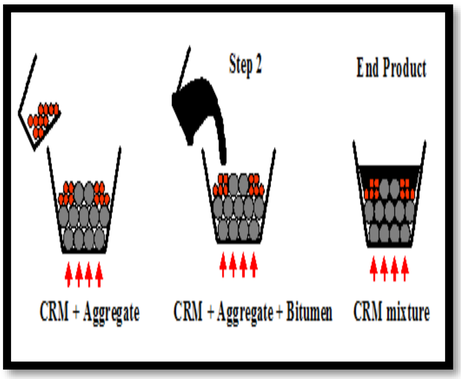


Figure 2.1: Wet Process method Figure 2.2: Dry process method

The main differences between these processes rubber many process is much coarser than wet process rubber, amount of rubber; the dry process uses rubber 2 to 4 times as much as the wet process, function of rubber; in the dry process it acts more like the binder, and finally the ease of incorporation into mix; the dry process no special equipment is equipment is required while in the wet process special mixing chambers, reaction and blending tanks, and oversized pumps and required.

2.3 Engineering Properties

Some of the engineering properties of CRM that are of particular interest when CRM is used in granular base application include gradation, bearing strength, compacted density, moisture content, permeability ,and durability.

2.3.1 Gradation:

The gradation for milled CRM is governed by the spacing of the teeth and speed of the pulvering unit. Wider tooth spacing and the higher speed results in larger particle sizes and coarser gradation.CRM can be readily processed to satisfy requirements for granular base and sub base specifications, such as AASHTO.

2.3.2 Compacted Density:

Due to coating of asphalt cement on RAP aggregate, which inhibits compaction, the compacted density of blended granular material tends to decrease with increasing CRM content.

2.3.3 Permeability:

The permeability of blended granular material containing CRM is similar to conventional granular base course material.

2.3.4 Ductility:

The ductility is a distinct strength of bitumen, allowing it to undergo notable deformation for elongation. The ductility is defined as the distance in centimetre, to which a standard sample or briquette of the material will be elongated without breaking. The finer rubber particles resulted in higher ductility elongation and also, that toughness would increase as rubber content increases (Mashaan et al., 2011).A combined effect of both time and temperature was noted with minimum elastic recovery value improved at maximum time and maximum recovery value of two hours and 240 Celsius, respectively (Jnesen et al., 2006).However, the modified binder was susceptible to decomposition and oxygen absorption. There were problems of low compatibility, because of the high molecular weight but the recycled tyre will decrease reflective cracking, which in turn increase durability.

2.4 Benefits using of Crumb Rubber

One of the major advantages of using CRM in road pavements is that, it can improve bitumen resistance to surface initiated cracks, the reduction of fatigue/ reflection cracking, the reduction of temperature susceptibility, improved durability as well as the reduction in road pavement maintenance costs (Liu et al., 2009).

Adding the crumb rubber provides a number of environmental, strength and economic benefits by reducing:

- Demand for aggregates;
- Demand for bituminous binders ;
- Waste

2.4.1 Reduced Demand for aggregates

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.

2.4.2 Reduced demand for bituminous binder

The quantity of additional bitumen asphalts is needed to produce road highway material is reduced because the CRM already contains some bitumen. This provides benefits in terms of reduced cost and lower energy demands with respect to both the production and distribution binders.

2.4.3 Reduced waste

Using CRM in pavement applications means that fewer waste materials are going to landfills. This saves valuable space in landfills. This is an important factor considering the cost of establishing environmental compliance for new landfill variations. Now, quantity of the waste tyres is increase every year, and it will be give the effect or impact to environment .The waste tyres very difficult to disposal because if use the wrong method to disposal it will give the effect. Therefore, when using this method to save the environment, it alsogives the benefits in economy and quality structure road pavement.

2.5 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

METHODLOGY

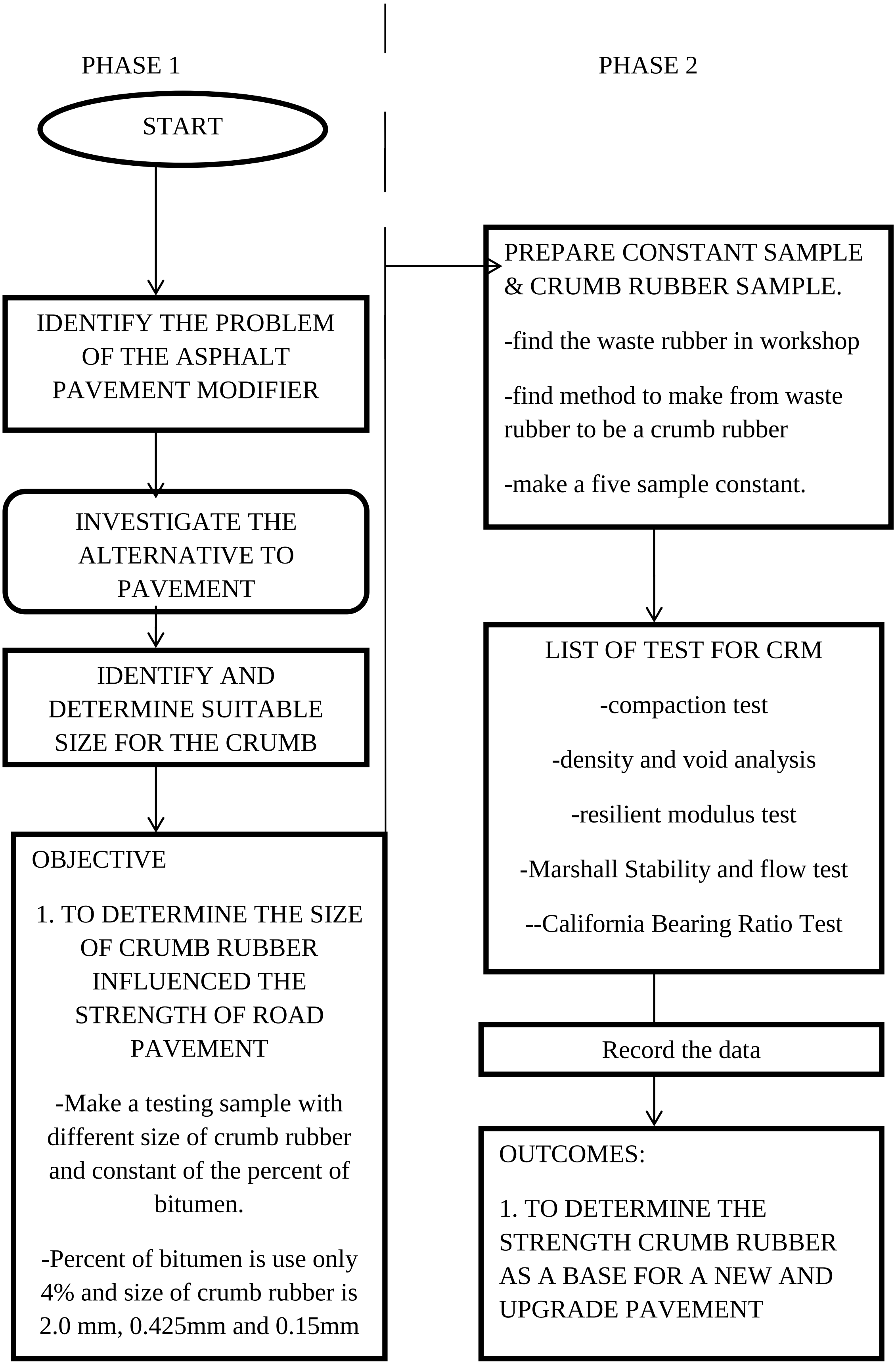
3.1 Introduction

As a continual of this chapter, the phases of work of study are determined. This is very important to be using it as a guideline to achieve the objective of the study. After the literature review completely did, the CRM as a useful additive is discussed. The methodology is consisted of several phases. Preliminary study is conducted to gain more information regarding to the proper method and analysis. After that, continue with the standard laboratory test conducted with Crumb Rubber Modified (CRM) and sieved aggregates (Crusher run).The following test like density analysis, void analysis, resilient modulus test, Marshall Stability and flow test were conducted. All the proper tools and equipment must be prepared earlier in order to avoid any problems when conducting the tests. Furthermore, the entire testing machine also needs to be checked to conduct the test smoothly.

3.1.1 Preliminary Studies

The purposes of preliminary studies are to gain information and early understanding about the project title and all the progress of the project. The data was collected from variety of resources such as journals, books, internet and information from the supervisor.

3.1.2 Research Flow Chart



3.2 Outline Methodology

A flowchart illustrating the experimental design for this study is including in Figure 3.1. A total of 36 binders (15 CRM and 15 controls samples while 6 samples with 3 different sizes of crumb rubber) were tested to measure the specific effects of crumb rubber modification. Six base samples, each being with a three different size of crumb rubber (2.0mm, 0.425mm and 0.15mm) were used to produce the CRM binders in the laboratory. Individual sizes were selected to minimize the effects of particle size gradation on the rheological properties of the CRM binders. Additionally, the best of size Of CRM were selected to represent the range of crumb rubber used to modify asphalt binders. CRM binders were produced with one rubber contents: 10% by weight of asphalt. Each CRM binder was produced in the laboratory using a mechanical mixer to blend the crumb rubber with the binder. Total weight of the each sample is 1200gram. After mixing, weighting, and compacting each of sample was tested. Then from the result, it will analysis, discussion and conclusion if the crumb rubber the best additives in road pavement.

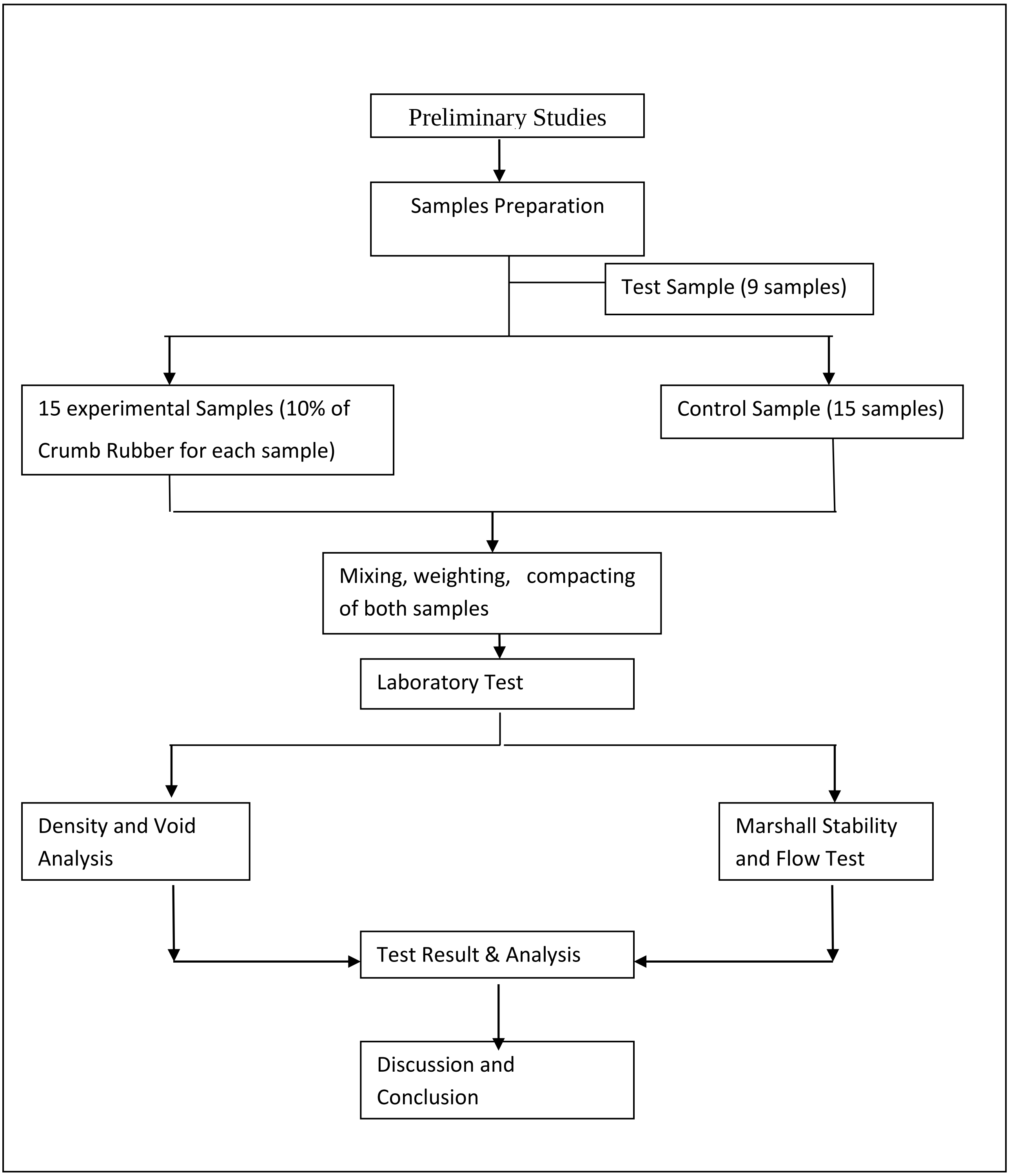


Figure 3.1: Flowchart of the Experimental Design

3.2.1. Samples Preparation

The samples preparation consists of the production of the Marshall Mix specimens. The total number of samples is 36 samples and it will be prepared in the laboratory with proper method and apparatus. The procedures are including the sieve of sample, mixing, weighting, compaction, and others according the ASTM standards.

The apparatus were used during the sample preparation are as followings:

I. Marshall Compactor
II. Mixer
III. Water Bath
IV. Marshall Compression Machine
V. Marshall Mould
VI. Sieve shaker
VII. Oven

Table 3.1 below shows the design bitumen content of mix. This study is only focussed on aggregate course wearing (ACW) design using the JKR standard. The range percentage of Bitumen or asphalt was used in this study is 4% until 6% because it is optimal percentage of a mix. Furthermore, the percentage of asphalt binder was constant to make sure other parameters not affected by the variety percentage of asphalt binder in the mix. Table 3.1.1, it shows number of samples prepared for the study. It consistsof 36samples and each percentage of CRM has 3 samples. The reading taken was the average value from the total 3 samples of each percentage. The average value guaranteed the better the accuracy to the results and the data was analyzed properly.

Table 3.1: Design Bitumen Contents (JKR/SPJ/1988)

ACW10 - Wearing course	5.0-7.0%
ACW14 - Wearing course	4.5 - 6.5%
ACW20 - Wearing course	4.5 - 6.5%
ACB28 - Wearing course	4.0 – 6.0%

Table 3.2: Number of total sample

	4.0% of CRM	4.5% of CRM	5.0% of CRM	5.5% of CRM	6.0% of CRM	Control Sample
ACW 14	9	3	3	3	3	15
Total Samples	36 Samples					

3.2.2 Sieve analysis to achieve proper aggregate gradation

Sieve analysis was carried out to find the suitable aggregates gradation for the mix. The aggregates were sieved according to the Jabatan Kerja Raya standard gradation graph to meet the specification. The proposed gradation for the samples was designed according to gradation graph analysis. The passing of the aggregates must be within the limit of the standard. Proper gradation can produced a better and suitable pavement for the road users. Table 3.3 shows the proposed gradation for the control sample without any CRM added.

Calculation Marshall Mix Design for Sample:

Total: 1200g

Table 3.3: Proposed Gradation for Control Samples

Passing Sieve Size(mm)	Retained on Sieve size(mm)	Total Percent passed (%)			% Diff	Weight of aggregate(g)
		Upper	Lower	Average		
20	20	100	100	100	0	0
20	14	95	80	87.5	12.5	150
14	10	90	68	79	8.50	102
10	5	57	52	62	17.0	204
5	3.35	62	45	53.5	8.50	102
3.35	1.18	45	30	37.5	16.0	192
1.18	0.425	30	17	23.5	14.0	168
0.425	0.15	16	7	11.5	12.0	144
0.15	0.075	10	4	7	4.5	54
0.075	pan	4	0	0	0	0
				Total		**1116**
Filler(1200g-1116g)						**84**

Table 3.4 Calculation Marshall Mix Design for Variable Sample

Passing SieveSize(mm)	Retained on Sieve size(mm)	Total Percent passed (%)			% Diff	Weight of aggregate(g)
		Upper	Lower	Average		
20	20	100	100	100	0	0
20	14	95	80	87.5	12.5	150
14	10	90	68	79	8.50	102
10	5	57	52	62	17.0	204
5	3.35	62	45	53.5	8.50	102
3.35	1.18	45	30	37.5	16.0	192
1.18	0.425	30	17	23.5	14.0	168
0.425	0.15	16	7	11.5	12.0	144
0.15	0.075	10	4	7	4.5	54
0.075	pan	4	0	0	0	0
Total						1116
Filler(1200g-1116g)						84

Calculation Bitumen for constant and experiment sample

$$4\% = \frac{x}{1200 + x} = \text{answer} \qquad \textit{(Equation 3.1)}$$

Calculation for Crumb rubber experimental sample

Every experimental sample has contains10% crumb rubberfrom the overall bitumen weight.The weighted of sample is 1200gram not include weight of bitumen and crumb rubber. Total weight of bitumen for 15 experimental samples is 854.49gram and total weight of crumb rubber is 95.1gram.

3.2.4. Sample Preparation Procedures

The aggregates were sieved to classify the size for proper gradation using the sieve shaker. The sieve is suitable for aggregates below 25mm. There are two types of shaker available in the laboratory which is small capacity and high capacity sieve shaker.

3.2.4.1. Preparation Aggregate

There are 36 samples prepared for this project.Three sizes of crumb rubber modified with every size need three samples to get average and fivetypes samples according JKR Standard specifications clauses 4.1.4also with 3 model for every types to get average. Similar sample sizes are to be prepared with 1200 gram weight plus wastage. To choose the right size crumb rubber, nine sampleswas produced and tested with different size crumb rubber (2mm, 0.425mm, and 0.15mm) and constant 4 percent of bitumen were bitumen. However, the aggregates from query sieved according to JKR specification clause 4.1.4.The aggregates were sieved to classify the size for proper gradation using the sieve shaker. The sieve is suitable for aggregates below 25mm. There are two types of shaker available in the laboratory which is small capacity and high capacity sieve shaker. Figure 3.2shows the machines which were used in the sieve analysis. The aggregates were sieved according to the gradation. The small capacity shaker is suitable for small quantity of aggregates while the high capacity sieve shaker is suitable for bigger scales of aggregates sieve process.

Figure 3.2: Sieve shaker and pan

The aggregates were weighted using the analytical balance as in Figure 3.2 above. A total of 1200grams of aggregates were weighted out which graded according to the ASTM and the aggregates was over dried at 180 ^{o} C for at least 4 hours. There were some precautions taken to achieve accurate readings such as the level of analytical balance and the proper reading of the balance.

Figure 3.3: Analytical balance for weighing the aggregates and asphalt.

Then asphalt was heated with temperature of 160ºC - 165ºC for at least 4 hours. The next step was weighing the Crumb rubber.Figure 3.3 shows the asphalt or bitumen was used for the sample preparations .The asphalt was weighted half from the total weight of bitumen of 1 sample and then heated in the oven.

Figure 3.4: Asphalt is weighted.

3.2.4.2. Preparation of Remoulded Sampling

The mould was 101.6 mm diameter by 76.2mm high and provided with a base plate and extension collar. Total 36 samples tested according to the CBR test. Each sample by CRM according to the proportion starts from 4%, 4.5%, 5%, 5.5% and 6.0%.Each sample is tested for three times to get the accuracy result.

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

2. A piece of filter paper was fitted in the bottom of the mould and the whole mix poured in three layers. The mix was then vigorously trowel 15 times round the perimeter and 10 times in the centre leaving a slightly rounded surface.

3. The mould was placed on the Marshall Compactor and was given 50 blows.

4. The specimen was then carefully removed from the mould and then marked. The specimen also was measured and weighed in air; water and saturated surface dry (SSD).

Figure 3.5: Sample was compacted into the mould

3.3Laboratory Test

The laboratory tests will be conducted to determine the properties of the asphalt after mixed with the crumb rubber. The test are includes Marshall Stability and flow test, density and void analysis and resilience modulus test.

The Marshall Stability and flow test provides the performance prediction measure for the Marshall Mix Design method. Furthermore, the density and void analysis is to determine the density, percentage air voids and percentage of aggregate voids filled with binder. The Marshall Apparatus is used to measure the resistance to plastic flow of cylindrical specimens of asphalt paving mixture loaded on the lateral surface. The resilient modulus test is use to find the resilient modulus.

The test is as following:

1. Density and Void Analysis (ASTM D2726)

2.Marshall Stability and flow Test (ASTM D1559)

3.3.1 Density and void analysis (ASTM D2726)

Density and void analysis were carried out to find the percentage of air void trapped in the sample. The samples were weighted in air; in water and saturated surface dry (SSD) condition .The sample was weighted on the analytical balance and the data was recorded for further analysis. The sample was immersed in the water tab to get the weight of sample in the water. The readings of the balance must be accurate and some precautions were taken to avoid parallax errors while taking the readings.

This test revealed the bulk density of the samples which can be used to find the voids in the mixture especially voids in total mix, voids in mineral aggregate and voids filled with asphalt. All this factors are very important to determine the density of the samples which is the factor that influencing the strength of the samples. Below are the method to calculate the bulk density and other parameters needed to find density and voids in the samples.

Bulk Density

$$\text{Gmb} = \frac{\text{Air}}{\text{SSD} - \text{Water}} \qquad (\textit{Equation}\ 3.2)$$

$$\text{Bulk Density. d} = \text{Gmb} \times \rho_w \qquad (\textit{Equation}\ 3.3)$$

Where,

d = Bulk density (g/cm³)

Gmb= Bulk Specific Gravity of the mix

ρ_w = density of water (= 1g/cm³)

WD = mass of specimen in air (g)

WSUB = mass of specimen in water (g)

WSSD = surface dry mass (g)

Voids in Total Mix (VTM)

The durability of bituminouspavement is a function of the voids of the mix (VIM). If too much voids in the mix, it is will provide passageways through the mix for theentrance of damaging air and water. Too low porosity couldlead to flushing where the excess bitumen squeezes out of themix to the surface. The high amount of crumb rubber particleabsorbs the binder which is required to encapsulate theaggregate and subsequently fill the voids between aggregates.High porosity in the bituminousmixture means that there aremany voids providing passageways for the entry of damagingair and water through the mix. On the other hand, with lowporosity, water flush occurs whereby bitumen is squeezedout of the mix to the surface(A.Mahrez, 2010).

$$\mathrm{Gmm} = \frac{1}{\frac{1-\mathrm{Binder}}{\mathrm{G_{se}}} + \frac{\mathrm{Binder}}{\mathrm{G_b}}} \quad (Equation\ 3.3)$$

$$\mathrm{TMD} = \mathrm{Gmm} \times \rho_w \quad (Equation\ 3.4)$$

$$\mathrm{VTM} = 1 - \frac{\mathrm{d}}{\mathrm{TMD}} \times 100 \qquad (Equation\ 3.5)$$

Where,

d = Bulk density (g/cm³)

Gmm=maximum Specific Gravity of the mix

ρ_w = density of water (= 1g/cm³)

TMD = maximum theoretical density (g/cm)

Pb= asphalt content, percent by weight of the mix

Gsc = Effective specific gravity of the mix

Gb = Specific Gravity of asphalt cement

Voids in the Mineral Aggregate

A minimum voids in the mineral aggregate (VMA)requirement, based solely upon the nominal maximum aggregate size.VMA criterion, while significant, is seen to be insufficient by itself to correctly differentiate sound from unsound mixtures.

$$VMA = 100 \times \left[1 - \left(\frac{G_{mb}(1 - P_b)}{G_{sb}}\right)\right] \qquad (Equation\ 3.6)$$

Gmb= Bulk Specific Gravity of the mix

Pb = asphalt content, percent by weight of the mix

Gsb = bulk Specific Gravity of aggregate

Voids filled with Asphalt

Voids filled with asphalt (VFA) are the void spaces that exist between the aggregate particles in the compacted paving HMA that are filled with binder. VFA is expressed as a percentage of the VMA that contains binder. Including the VFA requirement in a mix design helps prevent the design of HMA with marginally acceptable VMA. The main effect of the VFA is to limit maximum levels of VMA and subsequently maximum levels of binder content.

$$VFA = \frac{VMA - VTM}{VMA} \times 100 \qquad (Equation\ 3.7)$$

3.3.2 Marshall Stability and Flow Test (ASTM D1559)

The dimension and specifications of the Marshall apparatus are explained in ASTM D1559, gives a correlation ratio for stability of specimens not 63.5mm thick. Marshall Stability and flow test are conducted based on specific steps and procedure.

<u>The procedures of the stability and flow test are as a follows</u>:

1.The test was conducted in the laboratory using water bath and CBR. The test was specimens were immersed prepared according to the standard, in a water bath for 30minutes to 40 minutes or in an oven for 2hours at 60+1.0°C.Figure 3,5 shows the water bath used to immersed samples in the water with temperature 60°C for 40 minutes.

Figure 3.6: Shows the sample immersed in the water bath.

After , the sample were kept in the water bath for 30 minutes until 40 minutes, the samples then were removed from the water bath and placed in the jaw of the compression-testing machine for flow and stability test. The maximum time that's allowed between removal of the specimens from the water bath and maximum load is 30 second.

The sample was placed between heads and guide road. The guide road must be cleaned and lubricated within the process; the sample's temperature must be maintained between 21ºC - 37.8ºC. The placement of sample is shown in Figure 3.6. The specimens were removed from the water bath or oven then the lower jaw and the upper jaw were placed in position. The precaution for this experiment, the apparatus must adjust to zero.The load was applied to the specimen at a constant strain of 50.8 mm/min until the maximum load is reached.The maximum force and flow at that force were read and recorded.

Figure 3.7: The sample was placed in the testing head.

3.4. Data Analysis

The data was obtained from the experimental results which will be conducted in the laboratory will also through saves of analyses. Then data presented in from tables and graphs to show the results and comparison between each sample. This method also helps us to read the data clearer and easy to understand.

3.5 Summary

At the end of the last work, 6 samples with three different size of crumb rubber (2.0mm, 0.425mm and 0.15mm) designed according JKR Standard. The percentage of bitumen for 6 samples with three different crumb rubbers is 4%. A few testing will be carried out for this sample is Density and Void Analysis (ASTM D2726) and Marshall Stability and Flow test (ASTM D1559). Based on result, choose the best of size crumb rubber to produce 15 experimental samples and 15 constant samples. The range percentage of bitumen or asphalt for 15 experimental samples was used 4%, 4.5%, 5.0%, 5.5% and 6.0%.

The gradation of the combined coarse and fine aggregates, together with ordinary Portland cement added as an adhesion anti stripping. For design bitumen this project, using ACW14 JKR's standard. The weighted of sample is 1200gram not include weighted of crumb rubber and bitumen. The 15 experimentalsamples and 15 constant samples must be testing with Density and Void Analysis and Marshall Stability and flow test. From the testing, the result will be analysis using graph method. The analysis will compare between constant and experimental sample in terms of Voids Aggregate and Marshall Stability test. Analysis will discuss about Air Voids, Voids in the Mineral Aggregates (VMA), Voids filled with asphalt (VFA), Marshall Stability and flow test.

Chapter 4

Result and Discussion

4.1 Introduction

The data was collected is the standard laboratory test. All therecoded data use to conclude the project outcome. The results of the control samples were compared to the experimental sample to determine its properties and other apparent effects. The results from the experiments were presented in the graph and other data collection method. These methods give a clear view of the result where discussion can be made easily. The purpose of this study is to determine the effectiveness of crumb rubber in improving the properties of the Hot Mix Asphalt (HMA) in terms of air voids, stability, flow and stiffness. These properties can affect the strength and durability of the road which can lead to road defects and road accidents.In this chapter, all results from laboratory testing arediscussed. The tests results were presented in the table and graphs format to get clear of the outcomes. The analyzed results then were concluded in the next chapter where appropriated suggestions to improve the study was made.

4.2 Density and void analysis results.

The density and void analysis test were conducted using the analytical balance.The samples are weighted in air, water and surface dry mass (SSD).From these results, the bulk density was calculated to obtain other parameters which is maximum theoretical density (TMD), voids in total mix(VTM),voids in the mineral aggregate(VMA) and voids filled with asphalt(VFA).The results from the testing were recorded in the following Table 4.1, 4.2, 4.3 and 4.4 results of TMD, VTM, VMA, and VFA were calculated using the data from these tables.

Table 4.1 shows the result obtained from the Marshall Stability and void analysis of control samples. The results were calculated to gain the bulk density of the samples. From this bulk density, calculation of voids in total mix (VTM). Voids in the mineral aggregate (VMA) and voids filled with asphalt (VFA) can be obtained as a shown in Table 4.2.

Table 4.1: Marshall Stability and flow of constant sample.

Percent of samples	Numbers of samples	Height	Weighted			Marshall Stability	Flow
			Air	Water	SSD		
4	1	66.72	1221.6	671.7	1222.7	16.955	4.019
	2	66.94	1222.6	670.7	1221.7	10.110	5.430
	3	49.23	1221.6	670.0	1221.0	14.274	3.611
	Average	60.96	1221.6	671.0	1222.7	13.780	4.350
4.5	1	68.48	1231.1	692.5	1231.3	13.734	3.504
	2	66.96	1239.1	701.0	1240.0	16.137	3.593
	3	48.61	1230.5	692.0	1231.0	13.552	3.637
	Average	61.35	1233.6	695.2	1234.1	14.474	4.57
5.0	1	65.91	1230.1	696.3	1231.2	23.100	5.080
	2	66.26	1251.0	719.0	1253.9	14.674	3.925
	3	47.60	1232.2	700.0	1234.9	13.670	3.333
	Average	59.92	1237.8	705.1	1240.0	17.150	4.613
5.5	1	64.53	1246.8	705.8	1247.6	16.069	4.690
	2	65.30	1223.7	683.0	1224.8	17.313	3.679
	3	49.12	1263.6	723.0	1264.8	13.862	4.095
	Average	59.65	1244.7	703.9	1245.7	15.748	4.755
6.0	1	66.80	1237.3	701.5	1238.5	14.220	5.746
	2	69.95	1266.5	730.0	1267.0	16.137	5.095
	3	48.30	1252.2	716.0	1253.0	13.025	4.539
	Average	60.68	1252.0	715.83	1252.8	14.461	5.127

Table 4.1 show the result 15 constant samples for Marshall Stability and flow. The result gets from the testing Marshall Stability and Flow test. For this result, 3samples produced for each percentage to get the mean data.

<u>Example Calculation Bulk Density (g / mm³)</u>

Table 4.2: Bulk Density of Constant Sample.

Percent of samples	Numbers of samples	Weighted			Marshall Stability	Flow	Bulk Density
		Air	Water	SSD			
4	1	1221.6	671.7	1222.7	16.955	4.019	0.0022
	2	1222.6	670.7	1221.7	10.110	5.430	0.0022
	3	1221.6	670.0	1221.0	14.274	3.611	0.0022
	Average	1221.6	671.0	1222.7	13.780	4.350	0.0022
4.5	1	1231.1	692.5	1231.3	13.734	3.504	0.0023
	2	1239.1	701.0	1240.0	16.137	3.593	0.0023
	3	1230.5	692.0	1231.0	13.552	3.637	0.0023
	Average	1233.6	695.2	1234.1	14.474	4.577	0.0023
5.0	1	1230.1	696.3	1231.2	23.100	5.080	0.0023
	2	1251.0	719.0	1253.9	14.674	3.925	0.0023
	3	1232.2	700.0	1234.9	13.670	3.333	0.0023
	Average	1237.8	705.1	1240.0	17.150	4.613	0.0023
5.5	1	1246.8	705.8	1247.6	16.069	4.690	0.0023
	2	1223.7	683.0	1224.8	17.313	3.679	0.0023
	3	1263.6	723.0	1264.8	13.862	4.095	0.0023
	Average	1244.7	703.9	1245.7	15.748	4.755	0.0023
6.0	1	1237.3	701.5	1238.5	14.220	5.746	0.0023
	2	1266.5	730.0	1267.0	16.137	5.095	0.0023
	3	1252.2	716.0	1253.0	13.025	4.539	0.0023
	Average	1252.0	715.83	1252.8	14.461	5.127	0.0023

Use the equation 3.1 and equation 3.2 for the get the value of the bulk density. Below example shows calculation to get the bulk density value.

$$\text{Gmb} = \frac{\text{Air}}{\text{SSD} - \text{Water}} \, (Equation\ 3.1)$$

$$= \frac{1243.6}{1233.5 - 701.3} \qquad = 2.33g$$

$$BulkDensity.d \ = Gmd \times \rho_w \qquad (Equation\ 3.2)$$

$$= 2.33 \times 0.001$$

$$= 0.00233g/mm^3$$

From results as in Table 4.2, Voids in total mix (VTM), Voids in the mineral aggregate (VMA) and Total Marshall Density can be obtained from the bulk density. Use equation 3.3, equation 3.4 and 3.5 to get Voids in Total Mix (VTM) and Voids in the Mineral Aggregate (VMA).Below, show the example calculation:

$$\text{Gmm} = \frac{1}{\frac{1-\text{Binder}}{\text{G}_{\text{se}}} + \frac{\text{Binder}}{\text{G}_{\text{b}}}} \qquad \text{(Equation 3.3)}$$

$$\text{TMD} = \text{Gmm} \times \rho_{\text{w}} \qquad \text{(Equation 3.4)}$$

$$\text{VTM} = 1 - \frac{\text{d}}{\text{TMD}} \times 100 \qquad \text{(Equation 3.5)}$$

Table 4.3:Voids in Total Mix and Voids in the Mineral (VMA) for Constant Sample.

Percent of samples	Numbers of samples	Marshall Stability	Flow	Bulk Density	TMD	VTM	VMA
4	1	16.955	4.019	0.0022	0.00246	10.57	18.13
	2	10.110	5.430	0.0022	0.00246	10.57	18.13
	3	14.274	3.611	0.0022	0.00246	10.57	18.13
	Average	13.780	4.350	0.0022	0.00246	10.57	18.13
4.5	1	13.734	3.504	0.0023	0.00244	5.74	15.62
	2	16.137	3.593	0.0023	0.00244	5.74	15.62
	3	13.552	3.637	0.0023	0.00244	5.74	15.62
	Average	14.474	4.577	0.0023	0.00244	5.74	15.62
5.0	1	23.100	5.080	0.0023	0.00242	5.00	16.06
	2	14.674	3.925	0.0023	0.00242	5.00	16.06
	3	13.670	3.333	0.0023	0.00242	5.00	16.06
	Average	17.150	4.613	0.0023	0.00242	5.00	16.06
5.5	1	16.069	4.690	0.0023	0.00241	4.56	16.50
	2	17.313	3.679	0.0023	0.00241	4.56	16.50
	3	13.862	4.095	0.0023	0.00241	4.56	16.50
	Average	15.748	4.755	0.0023	0.00241	4.56	16.50
6.0	1	14.220	5.746	0.0023	0.00239	3.77	16.94
	2	16.137	5.095	0.0023	0.00239	3.77	16.94
	3	13.025	4.539	0.0023	0.00239	3.77	16.94
	Average	14.461	5.127	0.0023	0.00239	3.77	16.94

From Table 4.3, show the result TMD, VMA and VTM which get the value after using the equation 3.3, equation 3.4, and equation 3.5. The highest value for VMA is 18.13% and the lowest is 15.62.

Table 4.4: Voids of Filled Asphalt.

Percent of samples	Numbers of samples	Marshall Stability	Bulk Density	TMD	VTM	VMA	VFA
4	1	16.955	0.0022	0.00246	10.47	18.13	42.25
	2	10.110	0.0022	0.00246	10.47	18.13	42.25
	3	14.274	0.0022	0.00246	10.47	18.13	42.25
	Average	13.780	0.0022	0.00246	10.47	18.13	42.25
4.5	1	13.734	0.0023	0.00244	5.73	15.62	63.32
	2	16.137	0.0023	0.00244	5.73	15.62	63.32
	3	13.552	0.0023	0.00244	5.73	15.62	63.32
	Average	14.474	0.0023	0.00244	5.73	15.62	63.32
5.0	1	23.100	0.0023	0.00242	5.05	16.06	68.56
	2	14.674	0.0023	0.00242	5.05	16.06	68.56
	3	13.670	0.0023	0.00242	5.05	16.06	68.56
	Average	17.150	0.0023	0.00242	5.05	16.06	68.56
5.5	1	16.069	0.0023	0.00241	4.38	16.50	73.45
	2	17.313	0.0023	0.00241	4.38	16.50	73.45
	3	13.862	0.0023	0.00241	4.38	16.50	73.45
	Average	15.748	0.0023	0.00241	4.38	16.50	73.45
6.0	1	14.220	0.0023	0.00239	3.70	16.94	78.16
	2	16.137	0.0023	0.00239	3.70	16.94	78.16
	3	13.025	0.0023	0.00239	3.70	16.94	78.16
	Average	14.461	0.0023	0.00239	3.70	16.94	78.16

From Table 4.4 shows the value VFA for the constant sample. The highest value VFA is 78.16% this because percentage of asphalt is a higher than others percentage.

For Experimentsample, to define the suitable size for crumb rubber.3 sample with different size crumb rubber (2.0mm, 0.425mm and 0.075mm) was produced. To determine the suitable size for crumb rubber, Results from table 4.5, 4.6, 4.7 and 4.8 showing the result of bulkdensity,MarshallStability, flow, VTM, VMA, VFA, TMD and height will be used.From table 4.5, 4.6, 4.7 and 4.8 shows the result for 6 experimental samples.

Table 4.5: Marshall Stability and flow contain 3 different size of crumb rubber

Percent of bitumen and size of crumb rubber	Numbers of samples	Height	Weighted			Marshall Stability	Flow
			Air	Water	SSD		
4(2.0mm)	1	68.51	1251.3	703.9	1253.0	21.279	5.227
	2	67.91	1234.7	698.3	1236.3	18.680	2.873
	3	67.56	1232.8	693.2	1234.4	17.765	3.226
	Average	67.99	1239.6	698.5	1241.2	19.241	3.78
4(0.425mm)	1	68.26	1234.2	674.4	1237.2	13.824	4.000
	2	68.13	1243.0	700.9	1245.3	13.169	4.095
	3	67.58	1244.5	697.7	1246.0	14.195	3.729
	Average	67.99	1240.6	698.7	1242.8	13.730	3.941
4(0.15mm)	1	65.74	1240.5	695.0	1243.1	11.926	3.686
	2	68.53	1251.0	708.7	1253.7	13.061	3.761
	3	67.94	1232.2	692.2	1234.2	15.076	3.937
	Average	67.40	1241.2	698.6	1243.7	13.354	3.795

From Table 4.5, crumb rubber with the size 2.0mm showsthe highest Marshall Stability and the lower flow test.If compare the result depend on 3 different size, the suitable size is a 2.0mm because get the highest value than 0.425mm and 0.15mm.

Table 4.6: Result Bulk Density with contains 3 different size of crumb rubber.

Percent of samples	Numbers of samples	Weighted			Marshall Stability	Flow	Bulk Density
		Air	Water	SSD			
4 (2.0mm)	1	1251.3	703.9	1253.0	21.279	5.227	0.00228
	2	1234.7	698.3	1236.3	18.680	2.873	0.00229
	3	1232.8	693.2	1234.4	17.765	3.226	0.00228
	Average	1239.6	698.5	1241.2	19.241	3.78	0.00228
4 (0.425mm)	1	1234.2	674.4	1237.2	13.824	4.000	0.00219
	2	1243.0	700.9	1245.3	13.169	4.095	0.00228
	3	1244.5	697.7	1246.0	14.195	3.729	0.00227
	Average	1240.6	698.7	1242.8	13.730	3.941	0.00228
4 (0.15mm)	1	1240.5	695.0	1243.1	11.926	3.686	0.00226
	2	1251.0	708.7	1253.7	13.061	3.761	0.00230
	3	1232.2	692.2	1234.2	15.076	3.937	0.00227
	Average	1241.2	698.6	1243.7	13.354	3.795	0.00228

For each percentage of the experiment sample, the result show same value even different size crumb rubber. For the size 2.0mm, 0.425mm and 0.15mm crumb rubber, the value bulk density is a 0.00228.

Table 4.7:Result for TMD, VTM and VMA in samples with contain 3 different size crumb rubber.

Percent of samples	Numbers of samples	Marshall Stability	Flow	Bulk Density	TMD	VTM	VMA
4	1	21.279	5.227	0.00228			
	2	18.680	2.873	0.00229			
	3	17.765	3.226	0.00228			
	Average	19.241	3.78	0.00228	0.0025	7.31	15.91
4	1	13.824	4.000	0.00219			
	2	13.169	4.095	0.00228			
	3	14.195	3.729	0.00227			
	Average	13.730	3.941	0.00228	0.0025	7.31	15.91
4	1	11.926	3.686	0.00226			
	2	13.061	3.761	0.00230			
	3	15.076	3.937	0.00227			
	Average	13.354	3.795	0.00228	0.0025	7.31	15.91

Result shows the same value for Voids in Mineral Aggregate (VMA) and Voids in Total Mix with each percentage get the value is 15.91 and 7.31 respectively. Voids in Mineral Aggregate same value for each percentage because using the same type and amount of aggregate.

Table 4.8 Voids of filled Asphalt with contain 3 different sizes of crumb rubber

Percent of samples	Numbers of samples	Marshall Stability	Bulk Density	TMD	VTM	VMA	VFA
4 (2.0mm)	1	21.279	2.28				
	2	18.680	2.29				
	3	17.765	2.28				
	Average	19.241	2.28	0.0025	7.13	15.88	54.045
4 (0.425mm)	1	13.824	2.19				
	2	13.169	2.28				
	3	14.195	2.27				
	Average	13.730	2.28	0.0025	7.13	15.88	54.045
4 (0.15mm)	1	11.926	2.26				
	2	13.061	2.30				
	3	15.076	2.27				
	Average	13.354	2.28	0.0025	7.13	15.88	54.045

From the data in Table 4.5, 4.6, 4.7 and 4.8, the suitable size for crumb rubber is determine as the following Marshall Stability, flow, VTM, VMA, and VFA are presented in Table4.9, Table 4.10 , Table 4.11 and Table 4.12 respectively. In each sample, 10% of the overall sample's weight is represented by crumb rubber as binder agent. From the result, the best size of crumb rubber is 2.0mm.So it achieve the objective one to determine the suitable size of crumb rubber.

Table 4.9: Overall Results from 15 experimental samples

Percent of samples	Numbers of samples	Height	Weighted			Marshall Stability	Flow
			Air	Water	SSD		
4	1	68.51	1251.3	703.9	1253.0	21.279	5.227
	2	67.91	1234.7	698.3	1236.3	18.680	2.873
	3	67.56	1232.8	693.2	1234.4	17.765	3.226
	Average	67.99	1239.6	698.5	1241.2	19.241	3.78
4.5	1	66.41	1225.9	710.5	1227.6	17.286	3.662
	2	66.35	1209.3	704.9	1211.0	18.885	4.803
	3	66.73	1209.4	699.8	1209.1	21.785	3.652
	Average	66.50	1214.2	705.1	1215.9	19.319	4.089
5.0	1	66.11	1210.2	691.1	1213.6	17.011	3.762
	2	64.93	1193.6	685.5	1197.0	22.785	4.903
	3	65.22	1191.7	680.4	1195.1	18.890	3.752
	Average	65.42	1198.5	685.7	1201.9	19.562	4.139
5.5	1	66.92	1263.6	712.3	1265.2	16.861	5.694
	2	66.76	1247.0	650.3	1248.0	16.000	5.204
	3	67.07	1246.7	715.9	1249.1	15.658	5.003
	Average	66.92	1252.4	692.8	1253.3	16.173	5.301
6.0	1	67.16	1318.1	787.2	1314.5	15.861	5.694
	2	66.75	1257.1	668.3	1259.4	16.217	5.249
	3	66.96	1255.2	651.4	1258.2	15.307	5.705
	Average	66.96	1276.8	702.3	1277.4	15.795	5.549

The result for experimental samples with size of crumb rubber 2.0mm, the highest of value for Marshall Stability test is a sample with the percentage of asphalt 5.0%. Every sample has a 10% weight of crumb rubber per amount of weight of asphalt.

Table 4.10: Marshall Stability and Flow Test for 15 experimentalsamples

Percent of samples	Numbers of samples	Weighted			Marshall Stability	Flow	Bulk Density
		Air	Water	SSD			
4	1	1251.3	703.9	1253.0	21.279	5.227	0.00228
	2	1234.7	698.3	1236.3	18.680	2.873	0.00229
	3	1232.8	693.2	1234.4	17.765	3.226	0.00228
	Average	1239.6	698.5	1241.2	19.241	3.78	0.00228
4.5	1	1225.9	710.5	1227.6	17.286	3.662	0.00237
	2	1209.3	704.9	1211.0	18.885	4.803	0.00239
	3	1209.4	699.8	1209.1	21.785	3.652	0.00237
	Average	1214.2	705.1	1215.9	19.319	4.089	0.00238
5.0	1	1210.2	703.1	1213.9	17.011	3.762	0.00237
	2	1193.6	697.0	1197.8	22.785	4.903	0.00238
	3	1191.7	694.3	1195.1	18.890	3.752	0.00238
	Average	1198.5	698.1	1201.9	19.562	4.139	0.00238
5.5	1	1263.6	731.8	1265.8	16.861	5.694	0.00237
	2	1247.0	724.3	1248.0	16.000	5.204	0.00238
	3	1246.7	726.0	1249.8	15.658	5.003	0.00238
	Average	1252.4	692.8	1253.3	16.173	5.301	0.00238
6.0	1	1318.1	765.0	1314.5	15.861	5.694	0.00240
	2	1257.1	730.4	1259.4	16.217	5.249	0.00238
	3	1255.2	729.4	1258.2	15.307	5.705	0.00237
	Average	1276.8	741.6	1277.4	15.795	5.549	0.00238

The result shows,the bulk density range between for 15 experiment sample is 0.00228 until 0.00238 using Equation 3.1 and Equation 3.2.The factor can influence the value is a weight in air, weigh in water and SSD.

Table 4.11: Voids in Total Mix and Voids in Mineral Aggregate (VMA) for experimental sample.

Percent of samples	Numbers of samples	Marshall Stability	Flow	Bulk Density	TMD	VTM	VMA
4	1	21.279	5.227	0.00228	0.0025	8.8	15.91
	2	18.680	2.873	0.00229	0.0025	8.4	15.54
	3	17.765	3.226	0.00228	0.0025	8.8	15.91
	Average	19.241	3.78	0.00228	0.0025	8.7	15.79
4.5	1	17.286	3.662	0.00237	0.0024	1.3	13.05
	2	18.885	4.803	0.00239	0.0024	0.41	12.31
	3	21.785	3.652	0.00237	0.0024	1.3	13.05
	Average	19.319	4.089	0.00238	0.0024	1.0	12.80
5.0	1	17.011	3.762	0.00237	0.0024	1.3	13.5
	2	22.785	4.903	0.00238	0.0024	0.83	13.1
	3	18.890	3.752	0.00238	0.0024	0.83	13.5
	Average	19.562	4.139	0.00238	0.0024	0.99	13.37
5.5	1	16.861	5.694	0.00237	0.0024	1.3	13.96
	2	16.000	5.204	0.00238	0.0024	0.83	13.60
	3	15.658	5.003	0.00238	0.0024	0.833	13.60
	Average	16.173	5.301	0.00238	0.0024	0.99	13.72
6.0	1	15.861	5.694	0.00240	0.0024	0	13.33
	2	16.217	5.249	0.00238	0.0024	0.83	14.05
	3	15.307	5.705	0.00237	0.0024	1.3	14.41
	Average	15.795	5.549	0.00238	0.0024	0.71	13.93

Result above shows the data from TMD has decreasing 0.0001.In percentage 4.0% the value is 0.0025 and the others percentage is 0.0024.Result for VTM also decreasing with lowest value is 0.71 compare with VMA. The value of VMA unpredictable because at the first percentage the value increase 15.79 but decreasing at the second sample. After that, for other percentage is increasing for VMA value.

Table 4.12: Voids Filled with asphalt (VFA) results for experimental sample.

Percent of samples	Numbers of samples	Marshall Stability	Bulk Density	TMD	VTM	VMA	VFA
4	1	21.279	0.00228	0.0025	8.8	15.91	44.69
	2	18.680	0.00229	0.0025	8.4	15.54	45.95
	3	17.765	0.00228	0.0025	8.8	15.91	44.69
	Average	19.241	0.00228	0.0025	8.7	15.79	44.90
4.5	1	17.286	0.00237	0.0024	1.3	13.05	90.00
	2	18.885	0.00239	0.0024	0.41	12.31	96.67
	3	21.785	0.00237	0.0024	1.3	13.05	90.04
	Average	19.319	0.00238	0.0024	1.0	12.80	92.19
5.0	1	17.011	0.00237	0.0024	1.3	13.5	90.37
	2	22.785	0.00238	0.0024	0.83	13.1	93.66
	3	18.890	0.00238	0.0024	0.83	13.5	93.85
	Average	19.562	0.00238	0.0024	0.99	13.37	92.60
5.5	1	16.861	0.00237	0.0024	1.3	13.96	90.69
	2	16.000	0.00238	0.0024	0.83	13.60	93.90
	3	15.658	0.00238	0.0024	0.833	13.60	93.88
	Average	16.173	0.00238	0.0024	0.99	13.72	92.78
6.0	1	15.861	0.00240	0.0024	0	13.33	100.00
	2	16.217	0.00238	0.0024	0.83	14.05	94.08
	3	15.307	0.00237	0.0024	1.3	14.41	90.98
	Average	15.795	0.00238	0.0024	0.71	13.93	94.90

The percentage crumb rubber for every each sample is 10% with the size of the crumb rubber is 2.0mm only. The result was calculated using the voids and density analysis formula. The formula can be found in the appendix and some of the calculation involved.

4.3 Comparison between constant and Experimental sample in terms of Voids Aggregate and Marshall Stability Test.

The comparisons between constant sample and experimental sample needed because to confirmation the second objective is accepted. The value for experimental sample must be good than the constant sample. Use the graph method to make it a comparison between constant sample and experimental sample.

4.3.1 Analysis of Air Voids (AV)

Air voids are the important factor to correlate results to performance of the asphalt pavement. The amount of air voids affected the stability and durability of the mix. If the air voids are low, rutting can occur and if air voids too high, the mixes are permeable to air and water can cause premature cracking and ravelling of the mix. A proper percentage of air voids is necessary to prevent the pavement from flushing, shoving and rutting. It can be controlled by manipulating the binder content. The durability of an asphalt pavement is a function of the air void content.

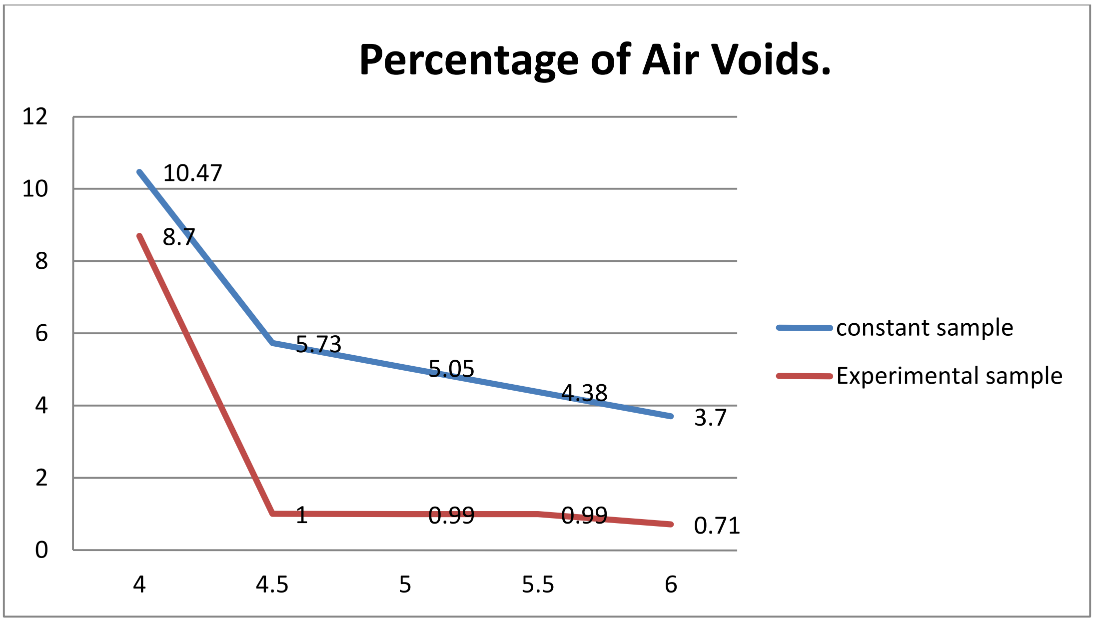


Figure 4.1: Graph of percentage of voids vs. Percentage of Bitumen.

The results of void and density analysis were presented using the graphical method to compare the effect of crumb rubber in each sample. The graph were built using the mean value of each percentage and expressed in the following graph. The graph in Figure 4.1 shows the percentage of air voids in the constant samples and experimental samples. The graph is directly proportional for constant sample and experimental sample. The amount of voids ratio in experimental sample lowers than constant sample. The higher the asphalt content, then the lower air voids content.

4.3.2Analysis of Voids in the Mineral Aggregates (VMA)

The voids in mineral aggregate or VMA is the Total volume of voids within the mass of sample with the sample is compacted. VMA is important toallow room for enough asphalt binder to make a durable mixture plus enough room for mixture air voids to ensure stable mixture. If percentage VMA in sample is low thus is a high possibility the binder cannot fully coated the aggregate in a mix. A durable asphalt mixture requires an adequate film thickness in a mixture. If the VMA amount is too large, an uneconomical amount of asphalt binder will be required to reduce the mixture air voids to an acceptable level. This amount of asphalt binder in the mixture may also lead to mixture stability problems. As the nominal maximum particle size of the aggregate increases, the minimum VMA required decreases. This occurs because the total void space between large aggregate particles is smaller than the void space between small aggregate particles (Roberts 1991).

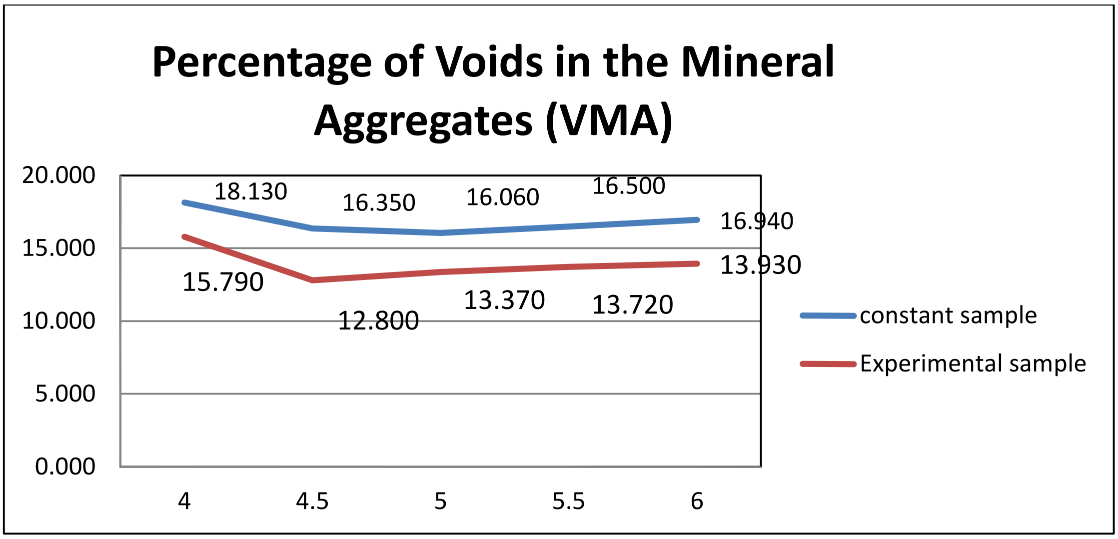


Figure 4.2: Graph of Percentage of Voids in the mineral aggregate (VMA) vs. percentage of Bitumen.

Figure 4.2 shows the graph of percentage of voids in the mineral aggregates (VMA) between constant sample and experimental sample.The VMA is purposed to measure the voids between the mineral aggregate particles in a compacted mixture. From the graph, it shows that the control sample has higher voids in mineral aggregate than variable sample.

4.3.3 Analysis of voids filled with asphalt (VFA)

It is percentage of the VMA; VFA can limit the amount of VMA. The purposes is to avoid less durable mixtures in light traffic applications.VFA is purposed to avoid less durable HMA resulting from thin films of binder on the aggregate particles in light traffic situations. Low air void contents may be very critical in terms of permanent deformation, the VFA requirement helps to avoid those mixes that are susceptible to rutting in heavy traffic situations.

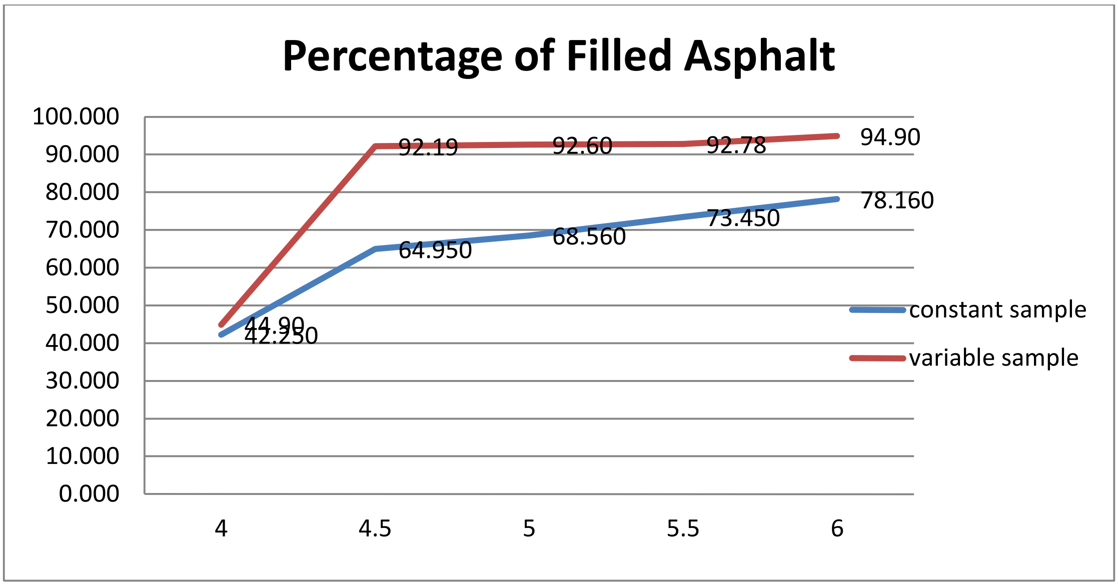


Figure 4.3: Graph of percentage Voids Filled with Asphalt

The graph in Figure 4.2 shows the percentage of voids filled with asphalt. The control sample has highest value than experimental sample.The higher value for VFA for constant variable and variable sample is 78.160 and 94.900 respectively. VFA determined by amount of VMA and air voids in the mixture.

4.4 Marshall Stability Test results

The mechanism of failure in the Marshall Test apparatus is complex but it is essentially a type of unconfined compression test. It can only have limited correlation with deformation in pavement where the material is confined by the tire, the base and the surrounding surfacing. Wheel tracking test have shown that resistance to plastics flow increase with reducing binder content whereas Marshall Stability is possible by considering flow and most agencies such as Malaysia’s JKR minimum for stability and maximum for flow for various purposes. The purpose of this test to measure the resistance to plastic flow of cylindrical specimens of asphalt paving mixture loaded on the lateral by means of the Marshall Apparatus.

Table 4.13:ShowsMarshall Stability and flow for constant samples

Percent of samples	Numbers of samples	Height	Height Correlation Stability	Marshall Stability	Corrected Marshall Stability	Flow
4	1	66.72	0.929	16.955	15.751	4.019
	2	66.94	0.877	10.110	8.866	5.430
	3	49.23	1.560	14.274	22.267	3.611
	Average	60.96	1.070	13.780	14.745	4.350
4.5	1	68.48	1.000	13.734	13.734	3.504
	2	66.96	0.900	16.137	14.523	3.593
	3	48.61	1.600	13.552	21.683	3.637
	Average	61.35	1.060	14.474	15.342	4.57
5.0	1	65.91	0.940	23.100	21.714	5.080
	2	66.26	0.938	14.674	13.764	3.925
	3	47.60	1.670	13.670	22.829	3.333
	Average	59.92	1.100	17.150	18.865	4.613
5.5	1	64.53	0.974	16.069	15.651	4.690
	2	65.30	0.956	17.313	16.551	3.679
2	3	49.12	1.560	13.862	21.625	4.095
	Average	59.65	1.110	15.748	17.480	4.755
6.0	1	66.80	0.940	14.220	13.367	5.746
	2	69.95	0.857	16.137	13.829	5.095
	3	48.30	1.620	13.025	21.101	4.539
	Average	60.68	1.040	14.461	15.039	5.127

Table 4.13 shows the values of Marshall Stability and flow for the control samples. The average value was calculated from the total number of 15 samples. The maximum Marshall Stability is 18.865Kn and Flow is 5.127.

Table 4.14: Marshall Stability and flow forexperimental samples

Percent of samples	Numbers of samples	Height	Height Correlation Stability	Marshall Stability	Corrected Marshall Stability	Flow
4	1	68.51	0.886	21.279	18.853	5.227
	2	67.91	0.8900	18.680	16.625	2.873
	3	67.56	0.908	17.765	16.131	3.226
	Average	67.99	0.900	19.241	17.317	3.78
4.5	1	66.41	0.935	17.286	16.162	3.662
	2	66.35	0.955	18.885	18.035	4.803
	3	66.73	0.930	21.785	20.260	3.652
	Average	66.50	0.952	19.319	18.392	4.089
5.0	1	66.11	0.959	17.011	16.314	3.762
	2	64.93	0.964	22.785	21.965	4.903
	3	65.22	0.958	18.890	18.097	3.752
	Average	65.42	0.998	19.562	19.522	4.139
5.5	1	66.92	0.925	16.861	15.596	5.694
	2	66.76	0.903	16.000	14.448	5.204
	3	67.07	0.920	15.658	14.405	5.003
	Average	66.92	0.924	16.173	14.944	5.301
6.0	1	67.16	0.918	15.861	14.560	5.694
	2	66.75	0.930	16.217	15.082	5.249
	3	66.96	0.925	15.307	14.159	5.705
	Average	66.96	0.925	15.795	14.610	5.549

Table 4.14 shows the values of Marshall Stability and flow for the samples with 10% crumb rubber. The highest value of Marshall Stability after the corrected is 18.662Kn and the highest value for flow is 5.549.

4.4.1 Analysis of Marshall Stability

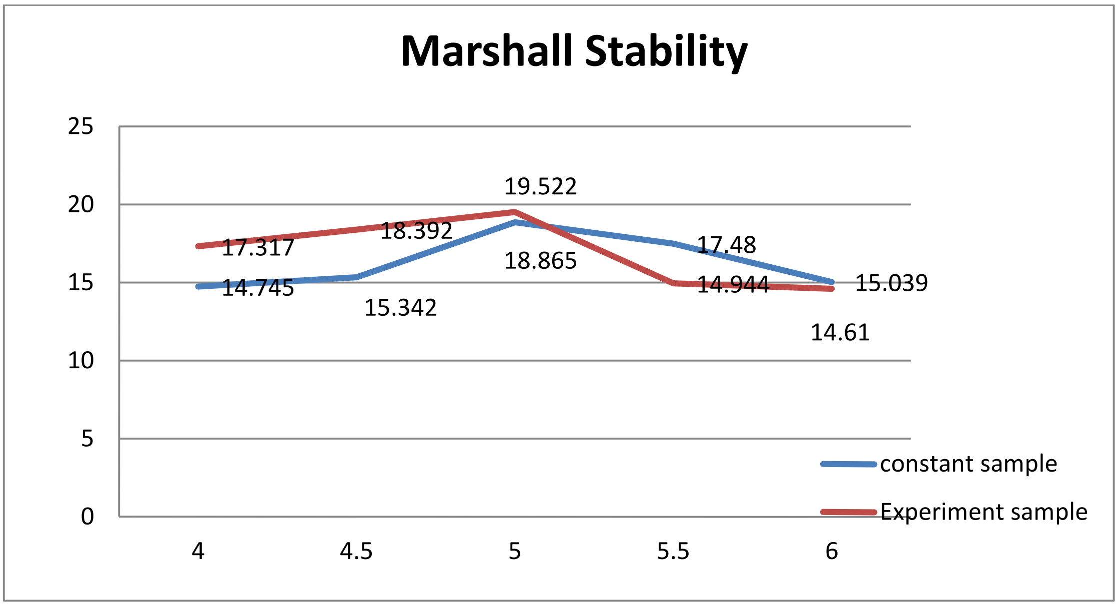


Figure 4.4: Graph Marshall Stability vs. Percentage of Bitumen

Figure 4.4 shows the value of Marshall Stability constant sample which was conducted along with flow test. Stability of HMA pavement is the ability of the mixture to resist shoving and rutting under traffic loads. The higher value in constant sample is 18.87kN compare before corrected Marshall Stability and the lowest value is 19.522kN.

The Stability of a pavement is the ability to maintain the shape of the layers under repented loading. The pavement is considered unstable when it develops ruts, ripples, ravelling and other sign of shifting the HMA, The stability should be adequate according to the requirement of traffic load of the area. It also depends on the frictional force between the aggregate particles known as interlocking force. It is mostly related to the aggregate characteristics such as shape, surface and particles.In Figure 4.4 shows the value of Marshall Stability for the variable sample which was conducted along with flow test. Stability of HMA pavement is the ability of the mixture to resist shoving and rutting under traffic loads.

4.4.2 Analysis of Flow

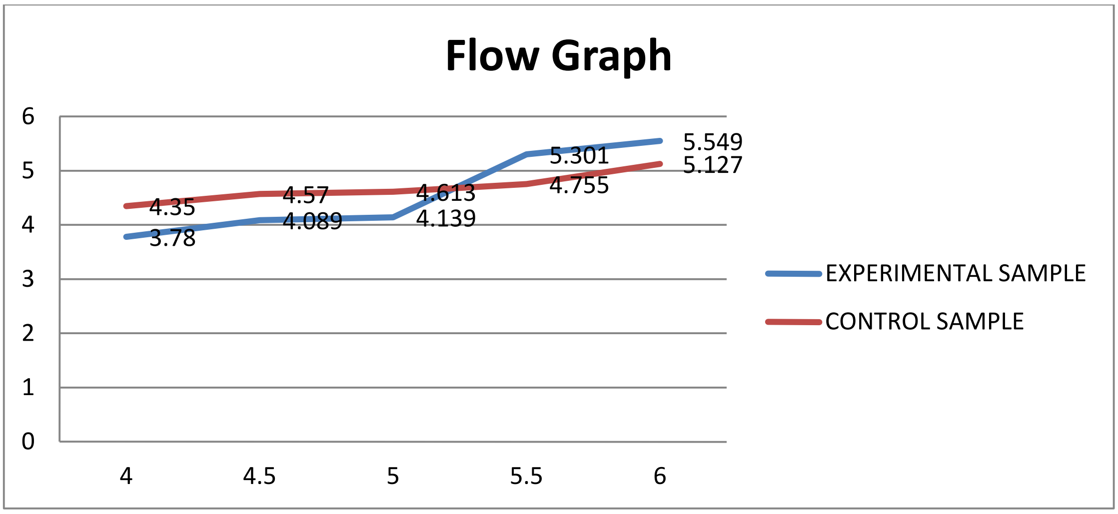


Figure 4.5: Graph of Flow vs. percentage of asphalt

Figure 4.6 shows the graph of flow against the percentage of asphalt. The highest flow is in experimental sample with 5.549 compare with the control sample. The flow of the experimental sample is increase at 5.5% and 6% than constant sample.Usually the crumb rubber deformation in HMA is mainly to the excessive binder content and low voids volume and normally forms when pavement temperatures are high. High value of crumb rubber flow in 5.5% and 6% are indicated that the pavement exposed to deform and can cause road defects and permanent deformation.

Based on result, crumb rubber suitable to be used as binder agent because this was shown there was no ravelling in all three porous asphalt testsections after the same period.This could be attributed tothe relatively thick film of binder coating the aggregatesand improved resistance to oxidative aging of the binderdue to the presence of either crumb rubber or proprietaryadditive(Roziawati, 2013). Furthermore, the addition of crumb rubber to asphalt or bitumen binders increases the rheological properties of the binders.The experimental sample has a low air void it shows high density and better for fatigue cracking resistance. The higher density reduces the potential of aging of the binder and hence reduces the potential of deterioration of fatigue resistance. Besides that,result shows the crumb rubber in experimental samples very high than constant samples hence it's very stability than Hot Mix Asphalt. The best of range VFA is 65-80, is specified on the basis of traffic levels-a higher volume of traffic.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

The last chapter of this study is the discussion and conclusion. Both written data regarding this study were obtained from the analysis of the experimental results. The conclusion of this study will be its main objectives. Furthermore, appropriate suggestions and recommendations were proposed in this chapter.

5.1 Limitation of Study

There were some major limitations of this study during cutting the crumb rubber manually. The problem is to cutting manually and produced the 3 different sizes of crumb rubbers. Besides that, mix bitumen and the crumb rubber also has a problem. From mixture it will produce something odour which it can make difficult to cooked. The last problem is a how to analysis the data. This is quiet tough because to relate many journal and book as a reference before make a analyses.

5.2 Suggestion for future research.

In the future research in this field, it is recommended that this project can use different size of crumb rubber such as not more than 1.0mm. It also can influence the result. For this thesis, the size of crumb rubber used is a 2.0mm, 0.425mm, and 0.15mm. This can vary the result of any analysis. As a known,for this project the size of crumb rubber produced by ambient process and maybe for the future, can use a cryogenics process to produce the crumb rubber and it can make it a comparison with this data. For the best value, it can add the new testing such as penetration bitumen and Resilient Modulus.

Uses the different percentage amount of crumb rubber in experimental sample one of the good suggestions to future research. This thesis, using 10% weighted from weight of bitumen. Example if weighted bitumen is 55.00gram so 10% from 55gram is a amount of the crumb rubber. So, for the future research percentage amount of crumb rubber will be increase. Therefore, it can increase the durability and strength of the road pavement and increase the quality.

5.3 Conclusion

For this research, it was revealed that the crumb rubber able to increase the compression strength of the pavement hence improve the properties of the pavement. It also improved the workability, durability and provided higher density of the Hot Mix Asphalt. Furthermore, it gave the pavement a better performance and higher quality pavement for the future development. This finding also helps to save the budget to pavement for the future development. This finding also helps to save the budget to maintain the road in a good condition all the time being. Thus, it is an economical method to be applied in the road construction in order to increase the strength of pavement. In the future, hopefully this finding can encourage new research to be conducted in the different ways and usage.

6.0 Reference

A.Mahrez. (2010). Properties and performance of stone mastic asphalt. International Journal of the Physical Sciences , 5(12), 8.

Al-maamori, M. M. (2014). Use of Crumb Rubber as a Way To Improve Performance Grade For Asphalt. Academic Research International , 5, 12.

Bahia. (2006). Modified Asphalt Binders For Paving Applications.

Bradley. (2006). Crumb Rubber Modification of Binders: Interaction and Particle Effects. Road Materials and Pavement Design , 23.

Darshna., (2013). Optimum bitumen Content by Marshall. Journal of Information Knowledge and Research,5.

H.Bahia, M. A. (n.d.). Modified Aspha;t Binders For Paving Application.

H.Bahia, m. A. (n.d.).Modified Asphalt Binders for Paving Applications.

H.Bahia. (2006).Modified Asphalt Binders For Paving Applications.

Kutay, M. E. (2012). Recent Research on Crumb Rubber Modified Binder Preparation Process.

Lee, S.-J. (2007). The effect of crumb rubber modifier (CRM) on the performance properties of rubberized binders in HMA pavements. Construction and Building Materials , 9.

Massimo Losa et al(2003). (n.d.). Crumb Rubber Modified Asphalt Concrete.

Mohamed, S. (2014).Asphalt Pavement Material Improvement: A Review. International Journal of Environmental Science and Development , 11.

Mohammed H.Al-maamori, M. M. (2014). Use of Crumb Rubber as a Way To Improve Performance Grade For Asphalt. Academic Research International , 5, 12.

MohdRasdan Ibrahim, 1. H. (2013). A Review on the Effect of Crumb Rubber Addition to the Rheology of Crumb Rubber Modified Bitumen. Advances in Materials Science and Engineering , 9.

Nabin, R. M. (2014). A study on the Performance of Crumb Rubber Modified Bitumen by Varying the sizes of Crumb Rubber. International Journal of Engineering Trends and Technology-volume 14 Number 2-Aug , 6.

Nabin.(2014). A Study on the Performance of Crumb Rubber. International Journal of Engineering Trends and Technology , 6.

Norhidayah Abdul Hassan et al. (2014). A Review of Crumb Rubber Modification in Dry Mixed Rubberised Asphalt Mixtures. JurnalTeknologi , 8.

Norhidayah Abdul Hassan et all. (2014). A Review of Crumb Rubber Modification in Dry Mixed Rubberised Asphalt Mixtures. JurnalTeknologi , 8.

Nuha.(2011). Effect of blending time and crumb rubber content on. International Journal of the Physical Sciences , 5.

Nuha. (2012). An overview of crumb rubber modified asphalt. International Journal of the Physical Sciences , 5.

Nuha. (2013). Performance Evaluation of Crumb Rubber Modified Stone. Hindawi Publishing Corporation , 9.

Presti, D. L. (2013). Recycled Tyre Rubber Modified Bitumens for road asphalt mixtures: A literature Review. Science Direct , 19.

Prithvi, P. (2006). Quality Control Requirements For Using Crumb Rubber Modified.

Roziawati. (2013). Do we need crumb rubber asphalt. JabatanKerjaRaya , 58.

S.kandhal, P. (1996). Precision of Marshall Stability and flow test using 6-in(152.4mm) Diameter specimen. 6.

7.0 APPENDIX