THE USE OF CRUMB RUBBER MODIFIED BITUMEN FOR CRACK MITIGATION-WET METHOD

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by

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CERTIFICATION OF APPROVAL

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

IVAN EDSON ISAIAS MINDO

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ABSTRACT

The present report entitled **"The use of crumb rubber modified bitumen for crack mitigation-Wet method"** discusses the usage of waste tyre rubber as a bitumen modifier. Waste rubber and the environmental impact it causes has been a concern for the past two decades all over the world, in particular industrialized countries. One environmental friendly idea to dispose the waste tyres is to add it into bituminous mixtures for the construction of roads.

The objective of this research is to find a good mix proportion for the rubberised bitumen. This project attempts to address two components to the problem: the environmental concern and the engineering properties of the modified mixture. The addition of rubber to the bitumen can aid on the mitigation of various distresses in highway pavements. Two main distresses in pavements are deformation (rutting) and fatigue (cracking).

The interaction between the bitumen and the crumb rubber can be done in the wet or dry process. The wet process is used for this study due to its added advantages, which are among others, the formation of a binding gel and the improved thermal susceptibility of the bituminous mixture. The selection of materials is as well pivotal in obtaining a good mix, test on the materials used are to meet the necessary specifications and material characterization. For this project the test methods used are from the British standards and the local JKR standards.

From the results, it can be concluded that the addition of crumb rubber into the bituminous mixtures using the wet method, improves the engineering proprieties of the pavement such as the fatigue resistance and the reduction of permanent deformation. Moreover, a high proportion of rubber, as high as 19.75%, was added to the bituminous mixtures, which help address the environmental problem related to rubber tyres.

Key Words: bituminous mixtures; rubber-bitumen; modified binder; pavement recycled waste tyres.

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LIST OF ABBREVIATIONS

AASHTO	American Association of transportation
ACV	Agregate crushing value
BS	British Standards
CRMB	Crumb rubber Modified Bitumen
g	grams
HMA	Hot mix Asphalt
HSE	Health Safety and Envirnment
JKR	Jabatan Kerja Raya
km	kilometers
kN	kilonewtons
LGM	Lembaga Getah Malaysia
m	meter
mm	millimeter
MPa	Mega pascals
NIOSH	National Institute Of Occupational Safety&Health
OBC	Optimum Bitumen Content
°C	degree centigrade
OPC	Ordinary Portland Cement
ORC	Optimum Rubber Content
ρ	density
Pa.s	Pascal second
PETRONAS	National Petroleum Company
PPE	Personal Protection Equipment
r.p.m	rotations per minute
R-B	Rubberised Bitumen
Sabita	South African Bureau of Transportation
SABS	South African Bureau of Standards
TMH	Technical Methods for Highways
SATCC	Southern Africa Transportation and Communication Council
SG	Specific gravity
TRH	Technical Recommendations for Highway
W	weight

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

The present report entitled "**The use of crumb rubber modified bitumen for crack mitigation-Wet method**" discusses the usage of waste tyre rubber as a bitumen modifier. The disposal of waste tyres encompasses a negative environmental impact that has been a concern for the past two decades all over the world. Moreover, most flexible highways present pavement distresses such as fatigue and deformation. The present study attempts to incorporate waste tyres into bituminous mixtures for the construction of roads, to improve the characteristics of the bituminous mixtures and to dispose the waste tyres. The introduction covers the background studies, the problem statements and the objectives and scope of the study.

1.2 BACKGROUND STUDIES

For the past century, many nations have invested massive amount of money and time on perfecting a mix of rubber and bitumen, with different objectives. At an early stage, the main objective was to find an environmental friendly method to dispose waste tyres, which take centuries to decompose and their combustion causes air pollution. Figure 1.1 shows the kind of stockpile that is normally associated with waste tyres. The reuse of these tyres is one of the world's greatest challenges, given the peculiar durability of about 600 years (Morilha Jr. and Greece, 2003).

Figure 1.1. Waste tyres stockpile

Due to the extensive research, it was also discovered that using the bitumen modified with rubber in asphalt was also good for cracking and rutting mitigation. Malaysia did not fall back, the research on this area started from the early 1950s, however the expected results were not yet achieved (Harun, 2004).

1.2.1 Pavement distress

Due to the increase of the traffic volume, temperature variations, or other loads over the wearing course, most highways with flexible pavements present structural failures or distresses such as cracking and rutting.

The two main mechanisms of deterioration of flexible pavements are: permanent strain (wheel track), caused by the combined action of the densification of materials, or mainly, by the shear fracture, and cracks due to fatigue. Fatigue cracks are deformation resulting from the repetition of horizontal traction underneath the wearing course (Bertollo et. al, 2002).

In light of these facts, it was suggested that the addition of crumb rubber in bituminous mixtures, could improve the performance of pavements in the field by increasing the flexibility. This application means that it can delay the onset of cracks, seal cracks and improve the existing waterproofing coating of asphalt (Oda, 2000).

The present dissertation is aimed at solving of the cracking problem in pavements by integrating waste tyres into the asphalt mixture, which will increase the elasticity thus reducing the probability of cracking.

1.2.2 Modified Bituminous Mix

Bituminous pavement are subjected to a variety of loading conditions which result in the development of internal tensile stresses, one source of failure which is likely to be induced in bituminous mixtures as a result of this inherent tensile characteristics in bituminous mixtures is cracking. A number of researchers have experimented with the use of various materials as addictives and modifiers in bituminous mixtures (Kamaruddin,1998).

Different materials have been experimented along the years of research in this area. Materials such as cotton, metal wires, asbestos, etc have been used as additives in bituminous mixtures. The mentioned materials were simply cancelled due to their side effect, that's where polymers were introduced to this field.

It is unrealistic to design an ideal bitumen modifier as each modifier has its own advantages and disadvantages. If the modifier reduces rutting it will most probably reduce the flexibility thus reducing the workability.

1.2.3 Crumb rubber as a Modifier

The use of rubber as a polymer added to conventional asphalt cement is not only a product which is merely placed just to be disposed, but rather serves as a great improvement of asphalt characteristics (Morilha Jr. and Greece 2003).

Waste tyres posed problems of environmental concern. A number of applications on the use of these used tyres have been attempted in various countries. Part of these attempts for the use of the wasted tyres is to improve the properties of bituminous mixtures.

The use of crumb rubber from waste tyres or tyre dust in bituminous mixes, shows itself as one of the few environmentally and technically accepted solution, that may bring major reductions in the volume of the waste materials in the world. (Cury et. al, 2002).

According to Zanzotto & Svec (1996) as well as Morilha Jr. and Greece (2003), the modified binder by the granulated rubber tyres or simply known as rubber-asphalt, presents some major advantages to their use, some are shown below.

- **Reduction of thermal susceptibility**: mixtures with asphalt rubber binder are more resistant to temperature variations, i.e. the performance both at high as at low temperatures is better when compared with pavements built with conventional binder;

• **Increased flexibility**: due to higher concentration of elastic fibres in rubber tyres and the increased capacity of adhesion of binder to aggregates, providing greater resistance to the propagation of cracks;

• **Greater resistance to aging**: the presence of antioxidants and carbon in rubber tyres help reduce the aging by oxidation;

• **Increase the softening point**, the rubberised bitumen binder has a softening point higher than the standard bitumen binder, thus improves the strength of wearing course.

As a result of the advantages mentioned above can highlight also:

• *Reduction of the thickness of asphalt pavement construction;*

• *Increase the useful life of the pavement;*

• *Better adherence tyre-pavement provided in use;*

• *Reduction of noise due to traffic between 65 and 85%;*

• *Reduction of the effect "spray"* in rain (mist that is formed when the vehicle passes over the wet asphalt), which contributes to the reduction in number of accidents and fatalities on highways.

1.3 PROBLEM STATEMENT

Waste tyres constitute a big environmental problem, as they occupy a large landfill area and take centuries to decompose organically. Combustion was used as a possible way to dispose the tyres however it also led to air pollution.

Structural failures in highway pavements such as cracks and rutting have always been an issue in highway construction and a big burden in the maintenance costs. Natural rubber has been used in asphalt mix for many years however the bitumen with this modifier is traded at a very high cost.

Crumb rubber it is a waste material, produced by fragmenting and pulverising waste tyres. The crumb rubber possesses similar characteristics as the natural rubber thus it can also be used to mitigate cracks at a lower cost. Using waste tyres in the asphalt also reduces the negative effect of waste tyres in the landfill areas.

New and more sustainable methods should be developed to solve to a certain extend both problems. The present report aims on improving the characteristics of the bitumen, consequently the asphalt, without compromising the quality and the cost. Moreover, using crumb rubber will certainly contribute to the reduction of the environment impact of waste tyres.

1.4 OBJECTIVES AND SCOPE OF STUDIES

The main objective of the present study is to compare, under controlled laboratory conditions, the performance of the bitumen modified with a optimum percentage of crumb rubber using the standard 80/100.

The objectives of this project are:

1. To identify the optimum percentage of crumb rubber as an additive to bitumen;
2. To optimise the percentage of crumb rubber into the mixture to solve the environmental component of the problem which is the mitigation of the tyre stockpiles on landfill areas;
3. To assess the different engineering implications and physical characteristics with the addition of crumb rubber into the binder mixture;
4. To determine the creep and fatigue resistance of the crumb rubber modified bitumen mixture as compared with the standard mixture;
5. To evaluate the economical implication with the use of crumb rubber modified bitumen mixture as compared with the standard mixture;

The advantages of using rubberised bitumen that are going to be explored in this research are as follows:

- Low permeability of the wearing course thus increasing the design life;
- Better response to thermal expansion, thus less prone to cracking;
- Due to the high compaction, better load resistance, etc.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Rubber bitumen it is an old concept however the technology is considerable new, taking into account the importance which is given to researches in this area lately. According to Specht (2000) & Cury et al. (2002), the first attempt to modify the properties of bitumen with rubber dates from 1898 in England, the patented process created a product called "rubber-bitumen".

It was only in the 1940s, when it all started in USA, when the company of recycling rubber, Rubber Reclaiming Company, entered to the market a product composed of recycled asphalt and rubber, called Ramflex (Morilha Jr. and Greece ,2003 & Salini and Marcon, 1998).

However, Charles H. McDonald is considered to be the father of the asphalt-rubber in the United States. In the year of 1963, he developed a highly elastic material to be used in the maintenance of asphalt pavements, consisting of asphalt binder and 25% of tire crumb rubber, which was called Overflex and in mid-1970, the Arizona Refining Company Inc. had created a new binder containing recycled rubber called Arm-R-Schield. (Salinas and Marcon, 1998).

Various experiments, road trial sections were done all over the world to perfect the mix on various weather conditions. Due to the thermal capabilities of the rubberised asphalt, the weather variations influence greatly the mix proportions. This justifies the need to analyse the research done in different locations of the world. The selection of material according to specifications is a pivotal component for a good research plan.

There are two methods of adding crumb rubber, dry and wet method and their intentions are different. This chapter explains the considerations done to select the wet method as to the dry method, it deals with the various experiments reported and papers published related to the use of crumb rubber as an add mixture of the asphaltic mixture.

2.2 EXPERIMENTS BY REGIONS OF INTEREST

The percentage of Crumb Rubber to be used as an additive to the binder varies from region to region depending on the atmospheric conditions and type of available aggregates. The following paragraphs explore some of the regions of interest for this report.

2.2.1 South East Asia

In South East Asia, the research on the use of rubber bitumen has started in the early 1990s. In this region, India is the country with considerable progress on this area. India has developed specifications for a standard mixture of crumb rubber modified bitumen (CRMB) called the "*Guideline Specifications on the use of Polymer and Rubber Modified Bitumen in Road Construction*" published in 1999 (Harun 2004).

In Malaysia after the Memorandum of Agreement (MOA) signed between Lembaga Getah Malaysia (LGM) and Jabatan Kerja Raya Malaysia (JKR) in 2002, many experimental road trials were constructed. The Memorandum agreed that both parties will take part on a joint project entitled *"The Use of Crumb Rubber as Bitumen Additive"*.

JKR had initiated a road trial using crumb rubber as an additive to bituminous mixtures. One of those road trials undertaken by JKR was a stretch of 5 km on the Kuala Lumpur - Kuantan bound. The objectives of the road trial were to compare the performance of dense graded bituminous overlay incorporating crumb rubber modified bitumen in mitigating reflective cracking with a similar overlay using conventional penetration grade 80-100 bitumen. In addition the road trial was also to assess the durability of porous asphalt incorporating crumb rubber modified bitumen as well as a proprietary modified bitumen produced by PETRONAS known commercially as BITUMINAS (Harun, 2004).

This experiment proved that the use of crumb rubber could significantly reduced the propagation of the cracks from underlying layers with the use of relatively fine aggregates and thin overlay. However the same results were not achieved with coarser aggregates and thicker overlays (Harun, 2004).

2.2.2 Southern Africa

The experiments on rubber bitumen have had an outstanding success over the past 20 years in South Africa (Potgieter, 2008). To highlight, the Buccleuch Interchange in South Africa, that endured for 16 years under a heavy traffic while it was expected to last for 10 years as per design. This interchange was the first monitored road trial section where rubberised bitumen was used (Potgieter, 2008).

There are various kilometres of roads using crumb rubber as a bitumen modifier in most of the countries in this region, being South Africa the leader in terms of research and development. Various standards and specifications were developed to govern the usage of the crumb rubber as an addictive to bituminous mixtures such as Sabita (South African Boreau of Transportation), SATCC (Southern Africa Transportation and Communication Council) and technical methods for bituminous mixtures with crumb rubber.

The main objective of using crumb rubber modified bitumen in this region is to reduce the occurrence of cracks, rutting and weaving. With the necessary attention to detail the expected life span can be as much as 20-years (Potgieter et al, 1998).

The somewhat higher initial construction cost of rubberised bitumen (R-B) asphalt are negligible in view of the savings in traffic accommodation, by-passes and the extended life rendered by the bitumen rubber asphalt overlay when assessed over the full life cycle (Potgieter , 2008).

2.2.3 The USA

USA is today the number one user of crumb rubber modified bitumen due to their environmental laws and policies (Harun, 2004). Each year, in the United States approximately 290,000,000 scrap tyres are produced, which translates to approximately 1 tyre/person/year (Amirkhanian and Franzese, 2001).

Since 1997 all federally funded highways have to contain not less than 20% of crumb rubber. The main concern in the USA was the disposal of waste tyres. Due to that requirement the USA is now, not only leading in the development of this technology but creating standards and specifications based on the various field and laboratory experiments conducted countrywide. Various road trial sections have been done in different states with different levels of success, which are then summarised at table 2.1.

2.3 MATERIALS

One important component of this research is the selection of appropriate materials which meet the specifications and/or can improve the characteristics of the standard bituminous mix. The materials for an asphaltic mixture are detailed as follows:

2.3.1 Binder

A binder is the most expensive and the pillar of the mix, the binder can be obtained naturally on asphalt lakes or by refining crude oil. The binder can be tar or bitumen (asphalt), however due to environmental and health consideration tar is seldom used. Different petroleum fields present different oil characteristics thus different properties of binders can be found. Through research and experience, standards and specifications on the required properties for bitumen to be used as a binder in an asphaltic mix were developed.

The major requirements for a binder are the viscosity of 20 Pa.s and a penetration of 80/100. To improve the characteristics of the binder, additives are incorporated in most cases polymers. Rubber is used as an addictive in various bituminous products such as the *Bituminas Premium –R* developed by PETRONAS and the *Shell Bitumen* developed, as the name suggests, by Shell Oil and Gas. Despite the fact that these two products have different compositions, they are both using natural rubber to modify the bitumen.

Crumbed waste tyre rubber is a cheaper and more sustainable approach compared to the natural rubber. From the extensive research and experiments two possible ways of adding rubber were implemented, namely: Wet-process and Dry-process;

2.3.1.1 Dry process

The rubber is added to the mixture as *filler*. The rubber replaces part of the filler such as Portland cement or any other filler. This mixture does not reduce the quantity of bitumen to be added however reduces the filler which may cause a lack of finer material as part of the rubber will be digested by the bitumen. For the bitumen to be used as a filler it has to be crumbed to a size of 0.075 mm, the standard size of a filler.

2.3.1.2 Wet-process

This process consists on the rubber being added and consumed by the bitumen in a mixing tank, capable of keeping the rotation at 3000 rpm for 45 minutes (Sabita,1988). This mixture is done at elevated temperatures to allow the blend and the formation of the *binding gel* which is the gel responsible for the added thermal capacities (expansion and contraction) of the bituminous mixture. Figure 2.1, shows the reaction stages of the asphalt and rubber and the formation of the binding gel.

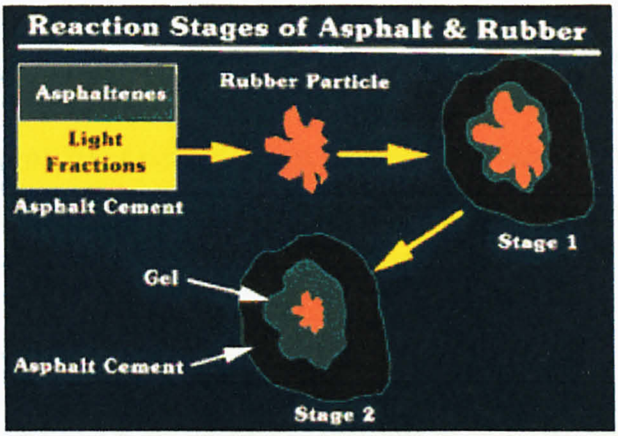

Figure 2.1. Interaction between the Rubber and the Asphalt by **Holleran G.**

The crumb rubber is added as a *bitumen filler system*, which means that it is blended into the bitumen before it is added to the asphalt. This means that the modification is done in the binder and from the literature review, this technically presents better results compared to the dry process where the crumb rubber is added as a filler in the bituminous mixture. The crumb rubber required to be added as a binder modifier has to be free from impurities such as metal and fabrics, and must be as pure as possible. Figure 2.2, shows a typical mixing setup for the asphalt and the rubber.

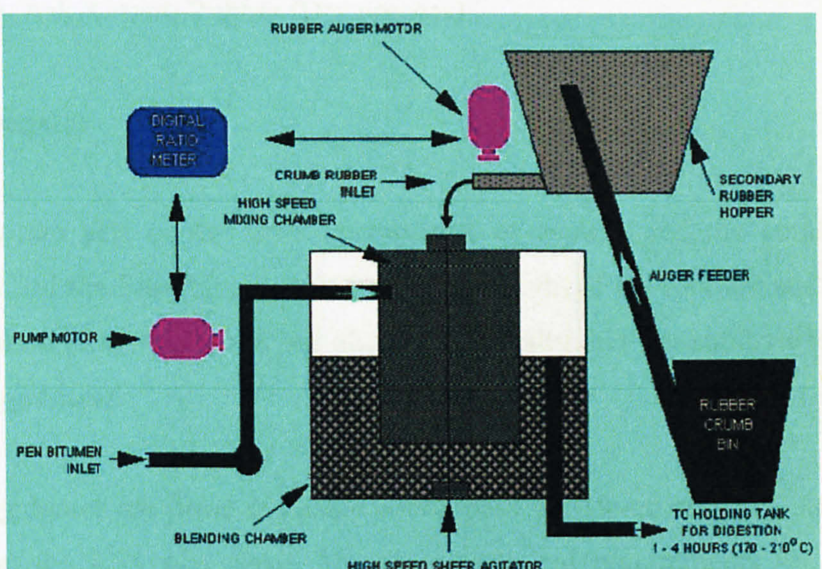

Figure 2.2 Blending of bitumen rubber [Potgieter C.,2008]

In sum, the R-B asphalt is manufactured using non-homogeneous bitumen rubber binder in terms of size. The binder is manufactured from blending penetration grade bitumen (60/70 or 80/100), plus extender oil (2%) plus rubber crumbs (18 – 24%) in a potent high-speed blender of at least 3000 r.p.m. (Potgieter, 2008). However, Lee and Amirkhanian (2006) reported that the mixture could also be blended at a lower blending speed of 700 r.p.m. For that, the blending temperature has to increase and or the size of the particles must reduce to increase the surface area.

2.3.2 Filler

Filler are fine particles added to the mixture to improve the mix by lowering the quantity of binder required to fill the voids thus reducing the cost without compromising on the safety of the design. The filler is also added to reduce the air voids therefore reducing the permeability and to improve the workability of the mix.

If the grading of the combined aggregates for asphalt surfacing mixes shows a deficiency in fines, approved filler may be used to improve the grading (Colto, 1988).

There are various materials which can be used as fillers, as long as they can pass the standard sieve Nº 200. Such materials could be Quarry Dust, Portland cement, Fly Ash, Crumb Rubber (Dry process).

2.3.3 Aggregates

Aggregates are part of the solid components of asphalt and the combination of aggregates and the filler take up to 95% of the weight of the mixture and up to 85% of the volume. The aggregates are obtained naturally and are subdivided in course and fine aggregates.

Course aggregates are those materials which pass the 19mm standard sieve and are retained on the 4.75 mm sieve. There are technical requirements for the course aggregate such as flakiness, aggregate crushing value, Mill Abrasion, etc.

Fine aggregate are the materials which pass the 4.75 mm sieve and are retained in the standard sieve Nº 200.

According to Colto (1988) the specification for the aggregates are as follows:

- The aggregate crushing value (ACV) of the coarse aggregate, must not exceed 25. The minimum dry 10% FACT values of the –13,2mm +9,5mm fraction must be at least 210 kN. The wet / dry ratio must not be less than 75%.
- The flakiness index for R-B surfacing asphalt must not exceed 25% for the 19,0mm and 13,2mm fraction and 30% for the 9,5mm and 6,7mm aggregate. In addition, at least 95% of all particles must have at least three fractured faces;
- The polished stone value of aggregate, when determined in accordance with SABS method 848, must not be less than 50;
- When tested in accordance with TMH1 (1986) methods B14 and B15, the water absorption of the coarse aggregate must not exceed 1% by mass, and that of the fine aggregate must not exceed 1,5% by mass, unless otherwise permitted;
- The total fine aggregate used in all asphalt mixes must have a sand equivalent of at least 50, when tested in accordance with TMH1*[1986]* method B19, and the natural sand where it is permitted to be mixed with the aggregate must have a sand equivalent of at least 30.

2.4. COST ANALYSIS

Crumb rubber modified bitumen compared with the standard bitumen has a higher initial cost; moreover the crumb rubber technology is more sensitive compared to standard bitumen (Potgieter, 2008). However in the long run, the usage of crumb rubber modified bitumen might lower the maintenance costs by improving the characteristics of the bituminous mixtures and at the same time it contributes to the betterment of the environment.

The addition of crumb rubber also improves the strength of the material against the ware and tare of the daily traffic. Thus the thickness of the pavement could be reduced comparing to the standard mix. This reduction in thickness may reduce the gap between the costs of both solutions (Amirkhanian, 2001). Overall, it is proven by various researches that the life cycle for a properly designed asphalt mix with modified rubberized bitumen it is longer than the standard mix under the same loads and the same design characteristics.

If the friction course for new roads can be constructed with the rubberized bitumen and this will increase its life cycle and reduce its maintenance cost. Although there will be an extra initial cost of about 15% this can be recovered through the reduction in the maintenance and long life cycle costs. The modified bitumen is supposed to give enhanced life of road surface by about 40 to 50 per cent and prove economical in life cycle costing (Indian road congress).

2.5 PAVEMENT DISTRESS

2.5.1 Cracking

The phenomenon of fatigue in the asphalt coating is evident in the form of cracks. Figure 2.3 shows a failed pavement due to fatigue. This phenomenon occurs due to the repeated traffic load and also due to the lack of flexibility or elasticity of the asphalt pavement, which cannot support the requirements of the heavy traffic without cracking (Martins, 2004).

Figure 2.3: Cracks on flexible pavement (Fernandes Jr et al., 1999)

The cracks due to fatigue are caused by several factors that occur simultaneously, usually the occurrence of these cracks is associated with repetition of heavy loads or when the number of applications exceeds the load projected value in design. (Bertollo et. al, 2002).

2.5.1.1 Types

Reflection cracks can occur in both directions and there are various types of crack paterns. According to Potgieter (2004) the most common crack patterns are as follows:

- **Crocodile cracking** – normally a traffic induced type of crack with initial longitudinal cracks in the wheel path followed by secondary transverse cracks, all to resemble the pattern on a crocodile's skin. Brittleness and other material deficiencies will accelerate the crack mechanism. The end result is a crazed and cracked area within the wheel path with closely spaced cracks, narrow in width (below 3mm) and very difficult to seal with crack infilling, normally recycling of the layer or a surface seal is applied.

- **Block cracking** – usually caused by shrinkage of cemented layers. Normally the cracks are far apart (3m or greater spacing) and wide (3mm or wider). These cracks lend themselves to infill sealing because the large width and because a surface seal will cover large sound areas, resulting in a waste of sealant.

- **Longitudinal cracking** – usually originates from poor construction or problem materials. Initially the cracks are wide open and suitable for a crack infilling type of seal. Exceptionally wide cracks can form when the fills settle and move, leading to cracks much wider than 15mm.

- **Transverse cracking** – this type of cracking is normally associated with cracks wider than 3mm and suitable for infill crack sealing. Blanket surface seal cover could then be wasteful.

2.5.1.2 Mechanism of Cracking

According to Nunn (1989), there are three possible mechanisms for cracking:

- Traffic induced fatigue;

  Caused due the movement initiated by the wheel loads passing over the cracks which in return induce shear stresses in the surfacing. The magnitude of these stresses could depend on:

  Thickness of the surfacing;

  Thickness of the lean concrete layer;

  The Subgrade Support;

  The granular interlock between the slabs;

- Thermally induced fatigue;

  Caused by the horizontal movement due to the expansion and contraction of underlying layers initiated by temperature changes.

- Surface initiated cracking;

  This type of cracking occurs when the bitumen mix becomes most brittle and its capability to accommodate the tensile strain caused by thermal contractions.

2.5.2 Pavement deformation

The early occurrence and/or excessive permanent deformation of the pavement asphalt, has been of great concern among researchers and engineers. The deformations that appear in the form of longitudinal depressions in the wheel tracks (Figure 1.3) are the result of accumulation of small deformations that occurs every time a load is applied.

This phenomenon has been aggravated due to the increased number of trucks and technological advances that enable vehicles to have higher axle load and higher pressure in the tires. (Fernandes Jr., 1994 & Bertollo et. al, 2002).

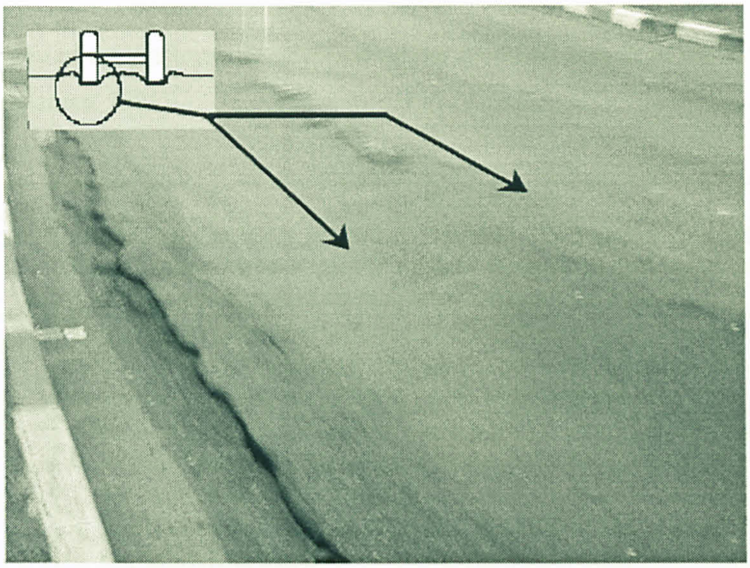

Figure 2.4: Permanent deformation due to the traffic load (Martins, 2004)

The collapse of the wheel track may be the result of the choice of thickness and the number of layers composing the pavement, resulting in incompatibility with the load capacity to support the stress (Martins, 2004). It might also be caused by deformation in bituminous layers, caused by mixtures which have little resistance to shear. In these mixtures, the sinking may be linked to the thermal susceptibility of ligands or the structure of households with low angles of internal friction. (Bertollo et. al, 2002).

Table 2.1. Summary of the performance of crumb rubber modified asphalt mixes in the US in 1970s and 1980s (Amirkhanian, 2001)

STATE		REMARKS
1	Alaska	Pavement sections placed in 1979 – 1983 using dry process (refer to Note below) have superior fatigue resistance but were not as good as conventional in resisting ravelling and pothole formation.
2	Arizona	The longest user of crumb rubber modified mixes, Arizona presently uses dense and open-graded mixes made with asphalt-rubber binders for overlays on existing rigid and flexible pavements.
3	California	After using crumb rubber for more than 20 years, California recommends; i. Asphalt-rubber open-graded mixes should no longer be considered as an experimental technology. ii. Asphalt-rubber dense and gap-graded mixes should be used on an experimental basis. iii. Dry process using devulcanised rubber should not be used.
4	Connecticut	Based on nine-year performance study of asphalt-rubber pavement produced using dry process, Connecticut concludes; i. On thick overlays, 2% crumb rubber increase reflection cracking as compared with control sections. ii. On thin overlays, 1% crumb rubber reduce reflection cracking by two-third. Increased in crumb rubber contents result in more cracking.
5	Florida	All asphalt-rubber dense and open-graded sections performed well since 1989-1990. Beginning in January 1994, all dense and open-graded friction courses require an asphalt-rubber binder.
6	Kansas	Two experimental asphalt-rubber dense-graded sections placed in 1990 showed more reflection cracking.
7	Michigan	Eight experimental sections constructed in 1978-1979 performed poorly in terms of reflection cracking and surface disintegration cracking. Michigan does not recommend the use of crumb rubber modified asphalt.
8	Minnesota	Three experimental sections did not show benefits which offset costs. No future sections were planned until more specific benefits were identified.
9	Mississippi	A test section with 6% devulcanised rubber showed little significant difference in crack pattern, skid resistance and rutting after 2 years as compared with the control section.
10	Oregon	After 5 years, rubber modified section showed better resistance to cracking. However, ravelling in the section was of concern.
11	South Dakota	Dry process rubber modified sections developed some potholes and break-up after 1 year which subsequently developed into large areas of delamination and peeling.
12	Texas	Of two sections, one ravelled shortly after construction while the other performed satisfactorily.
13	Utah	Dry process rubber modified section was removed after 3 years because of severe ravelling.
14	Washington	Five open-graded sections showed good to very good performance. Dry process sections showed poor to average performance.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

The research project took a year for the completion thus planning and organization were key features for a successful research. From the introduction, the objective of this research is to make use of the crumb rubber to interact with the standard bitumen to produce a modified binder. This requires an extensive literature review and laboratory work. The methodology used could influence greatly the final results thus this chapter is dedicated for the test methods and the laboratory procedures implemented in the present study.

3.2 EXPERIMENTAL WORK

The laboratory experiments are the core of the research, the properties of the bituminous mixtures are by well executed laboratory experiments. To ensure that the laboratory experiments present the expected results precautions are to be taken. The precautions include the use of appropriate equipment, use of accepted specifications, appropriate test methods and Health and Safety and Environment (HSE).

3.2.1 Equipment

The selection of the required equipment depends on two factors, namely, the required equipments as per specifications and most importantly the availability of the equipment in the Highway laboratory in Universiti Teknologi PETRONAS.

The equipment can be generalized as follows:

- Rotator mixer to blend the rubber with the bitumen;
- Bigger mixer to prepare the asphalt, mixing the solid components, aggregates, with the binder;

- Testing machines such as Marshall testing machine, Matta machine for the creep test and the flexural beam fatigue test.

3.2.2 Specifications & test methods

From the selection of materials to the test the trial mixes, standards and specifications are followed strictly to ensure the reduction of errors and increase the chances of attaining the required results. For this research the specifications & test methods to be applied are as follows:

Specifications

- Colto, 1988
- Sabita manual 19, 2007
- Indian Standards on CRMB
- British Standards 812, 594
- JKR Manual,1985

Test Methods

- Technical methods for highway TMH 1
- ASTM (American Society for Testing and Materials)
- Technical recommendations for highway TRH 4 & 14
- British Standards 812;

3.2.3 Heath, Safety and Environment (HSE)

The core of this research will be in the laboratory, the laboratory experiments involve potential hazardous chemical materials. A thorough research on the consequences and the handling of the chemicals it's required to select the proper personal protective equipment (PPE). The knowledge of the risks involved in the execution of the experiments is pivotal. For that reason a report on the hazards and prevention methods based on the NIOSH is to be compiled including the chemical report on the materials, fillers and binders. The sources of hazards for this research are the fine materials and the flumes produced in the reaction.

3.3 EXPERIMENTAL PROGRAMME & TEST METHODS

3.3.1 Experimental Programme

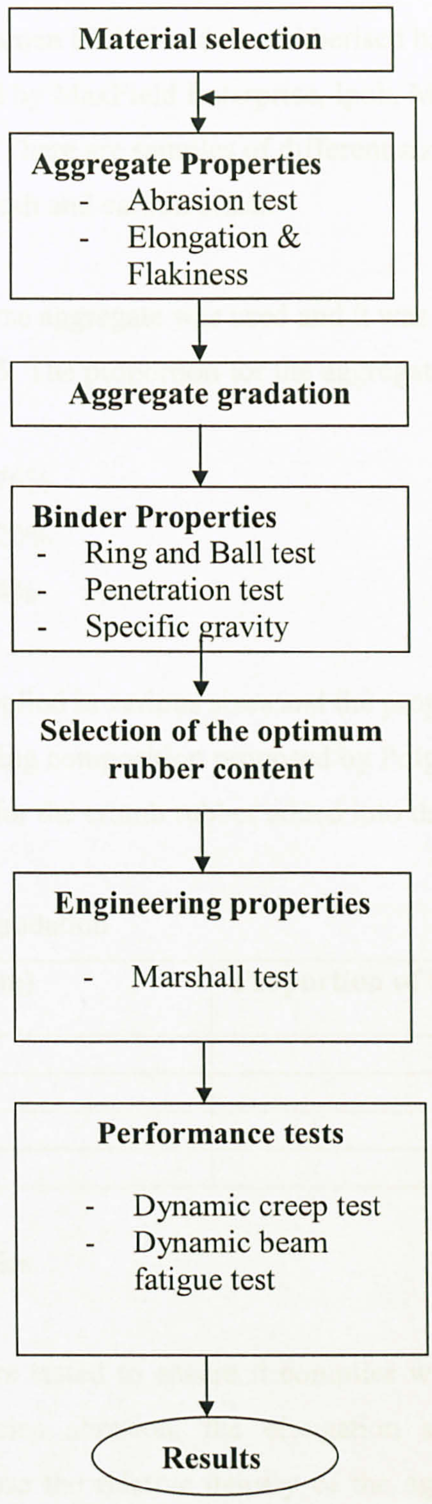

Figure 3.1: Experimental Programme

3.3.2 Material selection

For this study the mixture components were granite as the coarse aggregate, the river sand as the fine aggregate and the Ordinary Portland cement (OPC) as the filler. For the binder the standard bitumen 80/100 and the rubberised bitumen were used. The crumb rubber was supplied by MaxField Enterprise, Ipoh, Malaysia, and Ms Jenna, Kuala Lumpur, Malaysia. There are samples of different sizes of crumb rubber -60 mesh, -40 mesh and -20 mesh and carbon black.

A 14mm nominal size coarse aggregate was used and it was a dense graded mixture as per BS 594: Part 1: 1985. The proportion for the aggregate mixture was as follows:

Coarse aggregate: 76%

Fine aggregate : 20%

Filler : 4%

The crumb rubber was supplied in various sizes and the proportion to which it was added followed the following composition proposed by Potgieter (2008). Table 3.1 shows the gradation used for the crumb rubber added into the bituminous mixture.

Table 3.1: Crumb rubber gradation

Seive size (mm)	Proportion of Crumb rubber retained (%)
1.18	0
0.6	45
0.075	52.5
Pan	2.5

3.3.3. Aggregate properties

The coarse aggregate were tested to ensure it complies with the BS specifications, tests such as Los Angeles abrasion, the elongation and flakiness tests were conducted. To add to those the relative density of the aggregates was obtain, this figure aids in the calculation of the percentage of air voids. Please refer to Suhaimih's work for the description the tests.

3.3.4 Aggregate gradation

The grading in this study was done according to BS 594: part 1: 1984, the grading should lie within the following minimum and maximum values shown at table 3.2.

Table 3.2. The grading window for a dense mixture, 14mm nominal size aggregates

Seive size	**Specifications**	
20.000	Lower	Upper
14.000	100	100
10.000	95	100
6.300	70	90
3.350	45	65
1.180	30	45
0.075	15	30
Pan	3	8

For the mixture to lie within the window, the proportion of 76% coarse, 20% fine and 4% filler was used. This proportion was derived through trial and error.

3.3.5. Binder properties

The binder is mainly composed by bitumen, which is a thermoplastic construction material used due to its consistency. The consistency depends on the temperature and loading time (Kamaruddin, 1998). Due to its properties bitumen can be as fluid as water, at high temperatures, as well as near solid, at ambient temperature. That is a major advantage for highway construction.

The properties of bitumen could be distinguished as engineering and chemical properties. Looking at most applications of bitumen, the main interest lies in the engineering properties (Kamaruddin, 1998). Tests such as the penetration test, softening point test can give the basic engineering properties of the bitumen.

3.3.5.1 Penetration Test

This test is design to measure the consistency of penetration grade bitumen, in conformity with BS 2000: Part 49:1983. This test consists of a standard dimension needle, with a standardized weight of 100grams, is allowed to penetrate the sample for a standard time of 5 seconds, at a standard temperature of 25°C. The results of this test are presented on chapter 4 and figure 3.2 shows the apparatus of the penetration test.

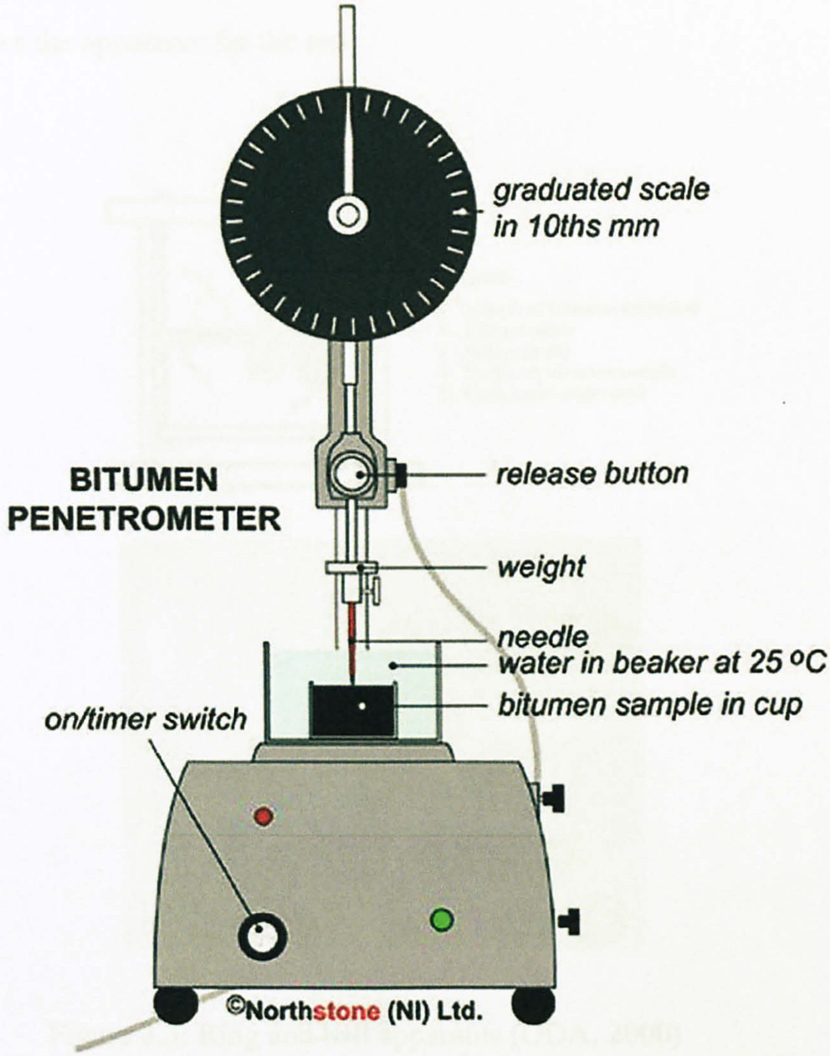

Figure 3.2 Penetration test apparatus

3.3.5.2 Softening Point (Ring and Ball) Test

Ring and ball is another test designed to measure the consistency of the bitumen. The test was carried out for each variation of crumb rubber added into the bitumen. The bitumen, with the increase of temperature, changes from semi-solid to liquid. The heat required for the bitumen to become liquid depends on each variation. The test measures the temperatures that which the different bitumen blends touch the plate, in other words it measures the softening point of the a binder which is defined as the temperature at which the test sample is soft enough to allow a standard 9.55mm diameter steel ball of mass 3.5grams to fall through a specified 25mm in a water bath. The temperature of the water bath is raised at a constant standard rate. This test was done in accordance to the BS 2000: Part 58:1983 and the results are in chapter 4. Figure 3.3 shows the apparatus for the test.

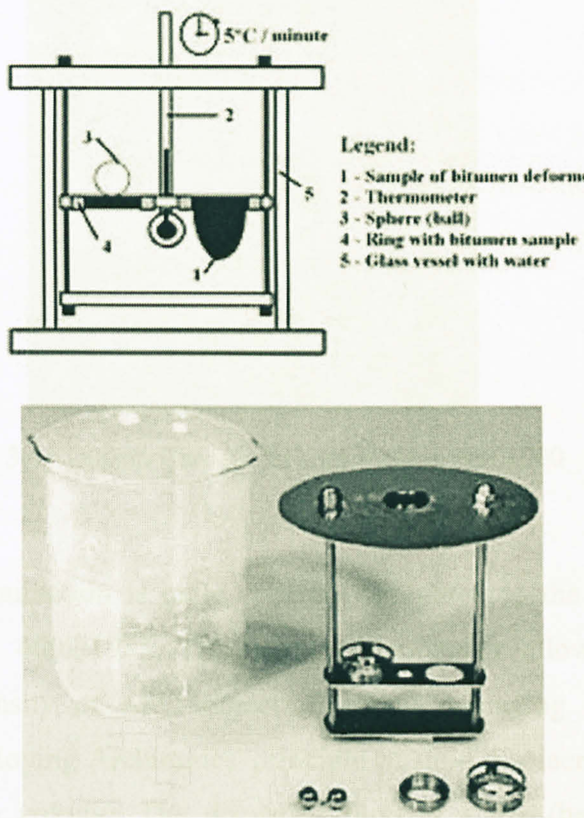

Figure 3.3: Ring and ball apparatus (ODA, 2000)

3.3.5.3 Specific Gravity Test

The specific density of the binder is an important test as the specific gravity result is required to determine the porosity of the mixtures of the binder and the aggregates. The test was performed to the standard 80/100 penetration bitumen and the various variations of crumb rubber bitumen blend, rubber-bitumen.

The specific density was obtained using the Quanta Chrome Helium Pycnometer 1000 shown at figure 3.4, available at the Chemical Engineering Department at Universiti Teknologi PETRONAS.

Figure 3.4 : Quanta Chrome Helium Pycnometer 1000

This method of determination is quite accurate compared to the standard method stipulated by the BS 4699:1985. The helium Pycnometer allows measuring the volume and true density of solid objects, without damaging samples. This is accomplished by employing Archimides' principle of fluid displacement and Boyle's law to determine the volume. The displaced fluid is a gas (helium) which can penetrate the finest pores, thereby assuring maximum accuracy. Due to the low specific gravity of the rubber it is expected that the blend has lower specific gravity then the control. The results of this test are presented in chapter 4.

3.3.6 Selection of the optimum rubber content

The proportion of rubber to add to the mix affects greatly its engineering and chemical properties of bitumen. The range of proportion of rubber added onto the bitumen at which better results of rubber-bitumen are from 16% to 24% (Amirkhanian, 2005).

The tests mentioned at 3.5.5 were conducted to determine the critical proportion to be tested against the standard bitumen. From the tests conducted it was observer that, for this quality of bitumen, the critical proportions were between 17% to 23 % thus 17%, 20% and 23% were selected for further tests.

3.3.6.1 Rubber- Bitumen Blend

For the rubber bitumen to form the required gel, as explained on point 2.3 of Chapter 3, it requires high shear, high temperature and a long contact time. For this study the shear of 637 r.p.m. was used due to the limitation of equipment in the Highway laboratory Universiti Teknologi PETRONAS, ideally a shear of 3000 r.p.m. produces better results. The temperature was kept at 190°C by a mean of a hot plate placed underneath the mixing pan. The pan was then covered to reduce the heat loss. The mix had a contact time of 45 minutes.

The equipment chosen for the mix can greatly influence the properties of the Crumbed Rubber Modified Bitumen. The equipment should be able to maintain a temperature of 200°C and be equipped with a mechanical agitator.
For this research the apparatus used was a heating plate capable of reaching temperatures over 250°C placed on the bottom of a mixer at 637 r.p.m. For temperature control the top was covered with a cupboard paper (figure 4.2). The mixture was done at an initial temperature of 190°C at a constant shear of 637rpm for 45 minutes.

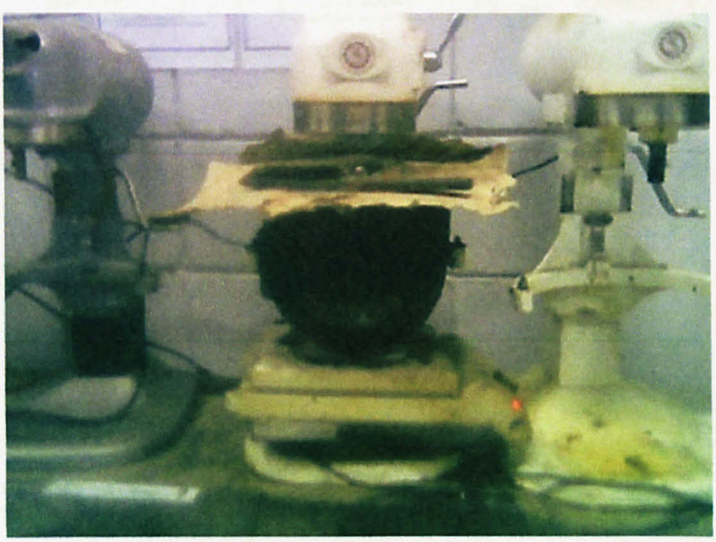

Figure 3.5 mixing apparatus

The binder mixture was a result of the addition of the crumb rubber using the wet method. Figure 3.6 shows the typical mixture considerations when adding rubber to bitumen. The binder consists of a mixture of bitumen of penetration 80/100 with crumbed rubber of specified gradation and proportion (16% to 25%) at a specified temperature (190°C) and shear, between 600 rpm and 3000 rpm (Martins, 2004).

This mixture is classified as a reaction and produces a binder with different properties of the original binder. Addictives may be added to adjust certain properties such as viscosity.

According to Kamar (2004) the degree of modification of the binder depends on the following:

- The type of tyre grinned ;
- The gradation of the crumb tyre particles;
- The proportion of crumb rubber added o the standard bitumen;
- The reaction time and temperature;
- The compatibility between the crumb rubber and the bitumen;
- The shear (speed) of the reaction;

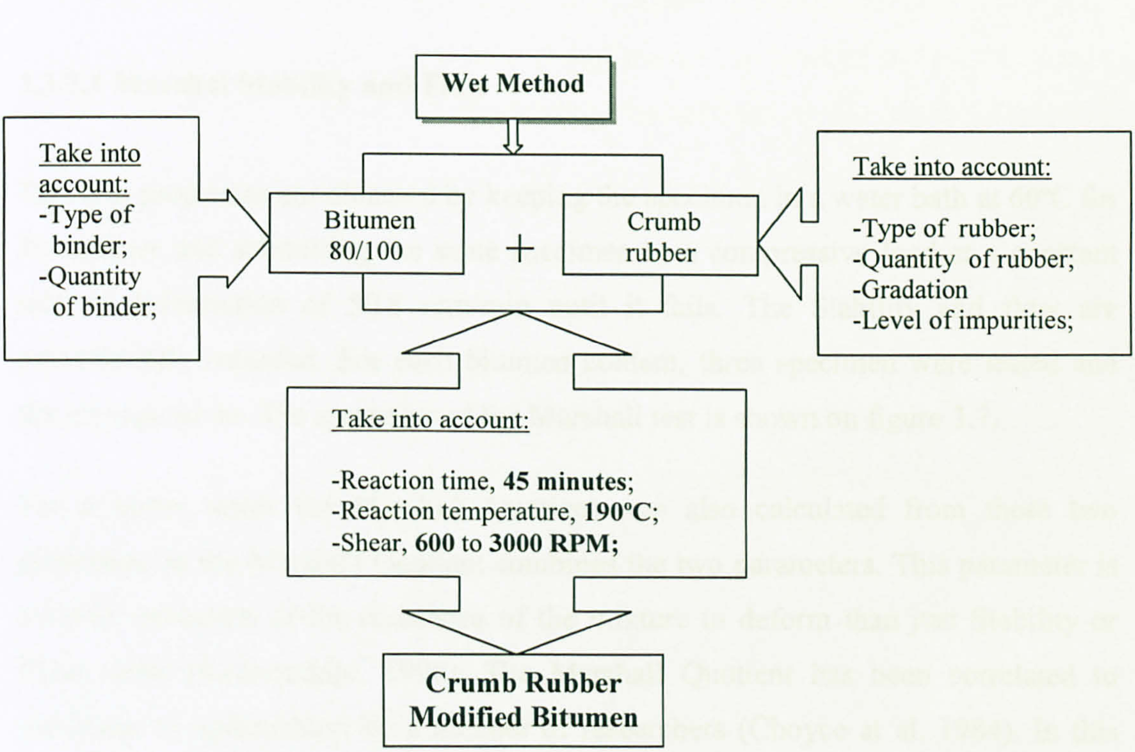

Figure 3.6. Wet process description

3.3.7 Engineering Properties of Mixtures

Many factors influence the behaviour and the performance of asphalt mixes, factors such as permeability, percentage of air voids, flow, stability etc. According to Kamaruddin (1998), when selecting the optimum binder content these factors are to be taken into consideration:

1. Maximum Stability;
2. Maximum density;
3. Minimum Permeability
4. Maximum Stiffness

To obtain these parameters the Marshall test procedure is used, based on the AASHTO. The Marshal test is the most common test used to determine the properties of bituminous mixes.
It consists of placing the sample under the Marshal compactor for 75 blows both sides at an initial temperature of 160°C. The Stability and the flow are determined by the Marshal testing machine, the other properties are obtained though calculations. The summary of the results are presented in chapter 4. The importance of each property is explained as follows:

3.3.7.1 Marshal Stability and Flow

This two properties are obtained by keeping the specimen in a water bath at 60°C for 30 minutes and submitting the same specimen to a compressive load at a constant rate of deformation of 50.8 mm/min until it fails. The Stability and flow are automatically recorded. For each bitumen content, three specimen were tested and the average taken. The apparatus of the Marshall test is shown on figure 3.7.

For a better result the Marshall Quotient was also calculated from these two properties, as the Marshall Quotient combines the two parameters. This parameter is a better indication of the resistance of the mixture to deform than just Stability or Flow alone (Kamaruddin, 1998). The Marshall Quotient has been correlated to resistance to deformation by a number of researchers (Choyce at al. 1984). In this study the Marshall Quotient was also taken into consideration.

Figure 3.7 Marshall testing machine

3.3.7.2 Workability

Workability in sum means the ease of mixture, laying and compacting of bituminous mixtures. The addition of crumb rubber to the bitumen, reduces its workability due to the addition of electrometers which increase the stiffness of the binder (Potgieter, 2004).

3.3.7.2 Density

The density of the specimen was obtained by measuring the weight in air and the weight in water of the same specimen. The volume is given by the difference of weight in air and in water. The density can be determined by the following formula:

$$\rho = \frac{W_{air}}{(W_{air} - W_{water})} \quad \text{(Equation 3.1)}$$

Where:

ρ – Density

W – Weight of specimen (grams)

3.3.7.3 Porosity

This property indicates the proportion of openings, pores in the bituminous mixture. One of the main purpose of the compaction is to increase particle interlock in the mixture and decrease porosity in the mix and thus increase durability of the bituminous mixture (Amirkhanian, 2005). The porosity is often related to the permeability if the voids are connected however the best relation is between the density and the porosity, the higher the density the lower the porosity and the inverse is true.

The porosity should be optimised to increase the durability of the pavement as well as prevent *flushing* to occur. Flushing is the phenomena where the excess bitumen is pumped out to the surface due to action of the traffic and high temperatures (Kamaruddin, 1998). Flushing is also responsible in reducing the fatigue life and the durability of the bituminous mixtures.

The addition of crumb rubber increases the percentage of voids (Potgieter, 2008) that. Using the dry method the porosity is higher compared with the wet method.

3.3.7.4 Permeability

The permeability of a bituminous mixture is measure of the ease of passage of air and water through it. The permeability depends on the size of the pores, the degree of inter-connectivity of pores, porosity, and the surface access of voids. The rubber bituminous mixture is expected to have relatively high permeability (Zanzotto, 1998).

3.3.8 Performance tests

For a clear comparison of the properties of the rubber-bitumen and the standard 80/100 bitumen, performance tests such as dynamic creep and the four point Flexural Beam Fatigue tests were conducted. The performance testes were conducted in the MATTA universal testing machine, present at Highway laboratory of Universiti Teknologi PETRONAS.

3.3.8.1 Dynamic Creep Stiffness Test

Good Correlation was found between the creep test and the rutting, thus the test is used to predict rutting results. The test was conducted at a constant chamber temperature of 40°C for 1800 cycles which lasts over an hour. Prior to the test the specimen is placed in the chamber of the MATTA machine to ensure that the skin temperature of the specimen is equal to the chamber temperature.

The specimens are preloaded for two minutes with a low pressure of 0.01MPa before being subjected for the high pressure of 0.10 MPa for an hour. Through the creep stiffness test results the relationship between the mixture stiffness and the binder stiffness could be obtained (Kamaruddin, 1998).

3.3.8.2 Flexural Beam Fatigue test

For this test a flexural beam fatigue device, shown in figure 3.8, contained in the MATTA universal testing machine, is used. The system is designed to conduct AASHTO T321, Standard Test Method for Determining the Fatigue Life of Compacted Hot-Mix Asphalt (HMA) Subjected to Repeated Flexural Bending. The test was conducted using the sinusoidal loading type for strain controlled mode. The device is enclosed in an environmental chamber which allowed the temperature to be kept at a constant 20 °C for the whole test period. The test stops when either one of the two conditions are observed: (1) the Flexural stiffness is lower or equal to the terminal stiffness or (2) The numbers of cycles is equal to 1 000 000 cycles.

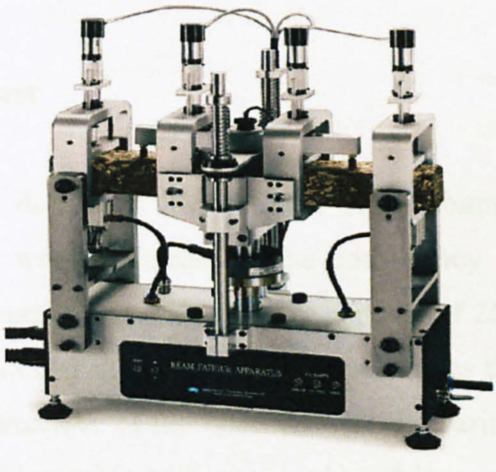

Figure 3.8: Flexural Beam Fatigue apparatus

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

The study was conducted through standardized laboratory test methods. The objective of the tests was to determine the characteristics of the materials, the optimized binder and rubber contents. The study also attempted to obtain the difference in engineering characteristics between mixtures containing the modified bitumen and mixtures containing the standard 80/100 bitumen.

All tests, except Specific Gravity (SG), were conducted at the Highway Laboratory at the Universiti Teknologi PETRONAS. The SG tests were conducted at the Chemical Engineering department at the same university. This chapter summarizes the results and the implications of the results onto the study.

4.2 TESTS, RESULT & DISCUSSION

To understand the physical, chemical and rheologic properties of the rubberised bitumen, standard tests were conducted, namely penetration, softening point and the specific gravity test. With the aid of these tests the properties of the modified bitumen could be obtained for each proportion of rubber added and compared to that of the base bitumen.

4.2.1 Penetration test

This test is used to determine the stiffness of the bituminous material through penetration, in other words it measures the consistency of the penetration grade bitumen. The test is carried out at standard conditions of 25ºC with a surcharge load of 100grams. The standard penetration needle penetrates the sample for 5 seconds. To understand the behaviour of the bitumen with the variation of the proportion of rubber content, the penetration test was conducted in a range of 16% to 24 % of crumb rubber added into the bitumen in one percent increment. Within the range of 16-24% of rubber added into the bitumen, better performance is expected (Potgieter, 2004). For each test, three individual samples were used and the average taken. Results of the penetration test are given in Table 4.1 and the graphic representation is given in Figure 4.1.

Discussion of the results

The results portray the fact that the incorporation of rubber resulted in harder bitumen as manifested by the reduction in penetration values. The values were reduced from the 80 to 100 dmm of penetration to an average of 24 dmm. By norm the lower the penetration grate will imply a high viscosity, thus the modified bitumen has high viscosity compared to standard bitumen.

From Figure 4.1 it can be observed that there is a s*ag* on the results at a proportion of 19.8% of crumb rubber added into the bitumen, therefore an addition of crumb rubber beyond this point will not increase the viscosity but decrease it, based on experimental results.

4.2.2 Softening Point (Ring & Ball) Test

The softening point test on bitumen was conducted to determine the temperature at which the consistency of the asphalt binder changes from a plastic or semi-solid state to a liquid state (Martins, 2004). This test is also used to obtain the consistency of the binder, in this case is through the temperature variation, the binder does not melt with an increase of temperature instead it gradually changes from semi-solids to liquid. The amount of heat required to change bituminous binders from semi-solid to liquid differs for different binders (Kamaruddin, 1998).

This test is carried out by the Ring and Ball method, which consists of suspending a brass ring containing the test sample of Bitumen in water at a given temperature. A steel ball is placed upon the bituminous material; the water is then heated at the rate of 5 ºC increase per minute. The temperature at which the softened bituminous material first touches a metal plate at a specified distance below the ring is recorded as the Softening point of the sample. Results of the Ring & Ball test presented in Table 4.2 and the graphic representation in Figure 4.2.

Discussion of the results

From the results it can be observed that the variation of the softening point with the percentage of crumb rubber added into the bitumen varies in an orderly manner. The increment of the crumb rubber proportion increases the softening point up until a threshold observed at about 20 % of crumb rubber, from this point the softening point reduces gradually. Thus from this observation the highest softening point is registered at 20% of crumb rubber added into the bitumen.

The softening point is generally higher for the crumb rubber modified bitumen compared with the standard 80/100 bitumen due to the rhetoric properties, in other words the mixture forms a gel which is responsible for the property change. The gel increases the binding properties and allows expansion with temperature increase (Potgieter, 2004).

4.2.3 Specific gravity determination

The specific density was obtained using the Quanta Chrome Helium Pycnometer 1000 available at the Chemical Engineering Department at Universiti Teknologi PETRONAS. The binder specific gravity is of utmost importance in the determination of the porosity of the bituminous mixture. Further description is presented in chapter 3. Results of the SG test are presented in Table 4.3 and the graphic representation in Figure 4.3.

Discussion of results

Observing the Table 4.3, it is evident that the incorporation of crumb rubber into the bitumen, to form a binder, reduces the specific gravity considerably. It is clear from Figure 4.3 that the specific gravity as the penetration and the ring and ball test present the results of SG increasing up until a threshold and it reduces gradually. The threshold is located at about 20% of crumb rubber added into the bitumen.

4.2.4 General discussion

From the result of the three tests it is clear that major changes of property occur around the 20% of crumb rubber added into the bitumen. For that reason, to narrow to the optimum rubber content (ORC), the 20% of crumb rubber and an offset of +/- 3% were used. Thus the proportions of rubber used on the Marshall test were 17%, 20% and 23%.

4.3 AGREEGATES

4.3.1 The gradation

The gradation for this mix is in accordance to the BS 594. The results obtained for the individual components of the aggregate mixture are presented in the Table 4.4. From those results, it was also possible to generate the optimum mix which would lie within the specifications. The proportion used for the coarse aggregates, fine aggregates and filler was in the proportion of 76% : 20% : 4% respectively. This is in line with the requirements of a well graded mix as proposed by JKR.

4.4 DETERMINATION OF THE OPTIMUM BINDER CONTENT

A good mix design is the backbone for an asphaltic mixture with sufficient strength and stability to meet the demands of traffic and sufficient workability to allow the placement on site to be done without segregation. At the same time the mix should have enough voids to ensure its durability.

The optimum binder content (OBC) was determined in this experiment using the Marshall Design method. The Marshall Design method takes into account the different factors that influence the behaviour ad performance of the bituminous mix. Therefore for each mixture five elements are considered in the determination of the OBC namely Stability, Flow, Marshall Quotient, mix density and air voids (porosity). The Figures 4.5 to 4.9 presents all the graphs from the Marshall test. From the figures, the results are summarized in Table 4.6 and the OBC was determined from its arithmetic mean.

From the results it was observed that the addition of crumb rubber has increased the required binder content, however the bituminous mix has, proportion wise, lower bitumen content. The results also show a higher air void content as we increase the percentage of crumb rubber into the binder mix. At 20% of crumb rubber it was observer that the required OBC was higher compared with the other two mixtures.

4.4.1 Determination of the Optimum Rubber Content

From the penetration test, density and the softening point it was observed that there is a deviation at 20% of crumb rubber thus to identify the ORC it was selected the 20% with an offset of +/- 3%. Therefore for the Marshal Test the following proportions were used 17%, 20% and 23% of crumb rubber added. From the graph given in Figure 4.10 it was determined that the ORC is 19.75%. At this point the optimum Bitumen content is at its highest thus ensuring the required binding characteristics of the binder are retained.

4.4.2 The characteristics at OBC and Optimum rubber content

From the Marshall Test it was observed that the Optimum Binder Content (OBC) of the crumb rubber modified bituminous mix was 5.95% and the Optimum Rubber Content (ORC) onto the binder mix of 19.75% against the OBC of 5.2% for the Standard bituminous mix.

Observing the results of the crumb rubber modified bituminous mix it can be determined that the Rubber will comprise of 1.175 % of the 5.95% of the OBC.
From there it can be calculated that the Standard 80/100 Bitumen will only be 4.77% of the whole bituminous mixture. Albeit the fact that the OBC is higher for the crumb rubber modified bituminous mix, there is a reduction of 0.43% of required standard 80/100 bitumen. Table 4.7 gives the summary of the characteristics of the optimum binders.

Table 4.7: The Characteristics of the mixtures at OBC

	OBC	Density	Stability	Flow	Marshal Quotient	VMA	Air Void %	Air Voids filled with bitumen
Control	5.2	2.35	10	2.9	4	16.5	5.2	66.5
19.75% crumb rubber added	5.95	2.275	10.9	3.0	3.51	19.3	7	65

4.5 PERFORMANCE TESTS

To evaluate the engineering properties of the bituminous mixtures, several tests were optimised to portray one or more characteristics of the asphalt mixtures. For this study the objective is to evaluate the creep resistance and the fatigue resistance of the modified rubber bituminous mix, thus the required tests were Dynamic Creep Test and the Flexural Beam Fatigue. With this tests it can be predicted the likelihood of cracking and rutting to occur.

4.5.1 Dynamic Creep test

The objective of this test is to measure the creep resistance, in other words the resistance to permanent deformation. The test is conducted in the MATTA universal testing machine at 40°C at a constant stress of 0.1 MPa for a period of an hour. The cumulative deformation is recorded. The creep resistance and the cumulative deformations were plotted against the number of cycles. Figures 4.14 and 4.15 respectively, show the comparison between the modified crumb rubber bituminous mix and the control mix.

From the results it is observed that the modified bitumen presents higher creep resistance compared with the control and the permanent deformation of the modified mix is lower compared with the standard bituminous mixture. This simply means that the modified bituminous mixture can take more load as compared to the control and best of all it is more resistant to deformation, thus the probability of rutting occurrence is lowered with the addition of crumb rubber.

Analysing Table 4.8, which presents the summary of the creep test it can be seen that for the same mixing conditions and aggregate proportions, the modified bituminous mixture has far greater creep stiffness. Amirkhanian (2001), reports that the creep stiffness of the modified binder with crumb rubber at specified conditions could be at least twice the creep resistance of the standard bituminous mixture. Being the specific conditions as follows: Shear of 3000 r.p.m, temperature of 190°C, at a contact time of 45 minutes.

Table 4.8: The summary of the creep results

	Creep test	
Creep stiffness (MPa)	Control	Rubber Modified Asphalt
	13.1	16.5
	19.2	17.7
	14.5	9.5
AVERAGE	13.8	17.1

4.5.2 Flexural Beam Fatigue test

Pavement distresses are also caused by stresses due to fatigue, one example is cracks. If the mixture is not able to respond the loads due to fatigue it will certainly fail. To test how much is the fatigue resistance of the mixtures, the flexural beam fatigue test is used. This test is conducted in the MATTA machine, at a temperature of 20°C until the beam reaches its terminal stiffness or it reaches 1 000 000 cycles.

From the results presented in Figure 4.15, it can be observed that the average time required for the modified bituminous mixture to reduce from the initial stiffness to the terminal stiffness is at least five (5) times longer compared with the standard bituminous mixture.

This implies that the crumb rubber modified binder responds better to stresses caused by fatigue. This response is done gradually, the graph of the modified bituminous mixture shows that the slope is gentle as compared with the standard mixture which looses relatively quickly its flexural stiffness.

The initial stiffness of the modified bituminous mixture its lower compared with the standard bituminous mixture. The elastometers added into the bituminous binder mix and the increased air void proportion, reduce the flexural stiffness of the asphalt mixture. Due to this flexural stiffness reduction the wearing coarse responds better to loads and due to its high creep stiffness it returns back to the original condition with no or negligible deformation.

The flexural amplitude is higher for the modified bituminous mixture, due to the same reasons as the above observation. The addition of crumb rubber increases the fatigue resistance and thus reduces the possibility of cracks.

Table 4.1: Penetration results

Rubber content (%)	Average penetration (dmm)
16	67
17	40.1
18	24.4
19	21.8
20	16.4
21	23.5
22	23.75
23	25.5
24	30

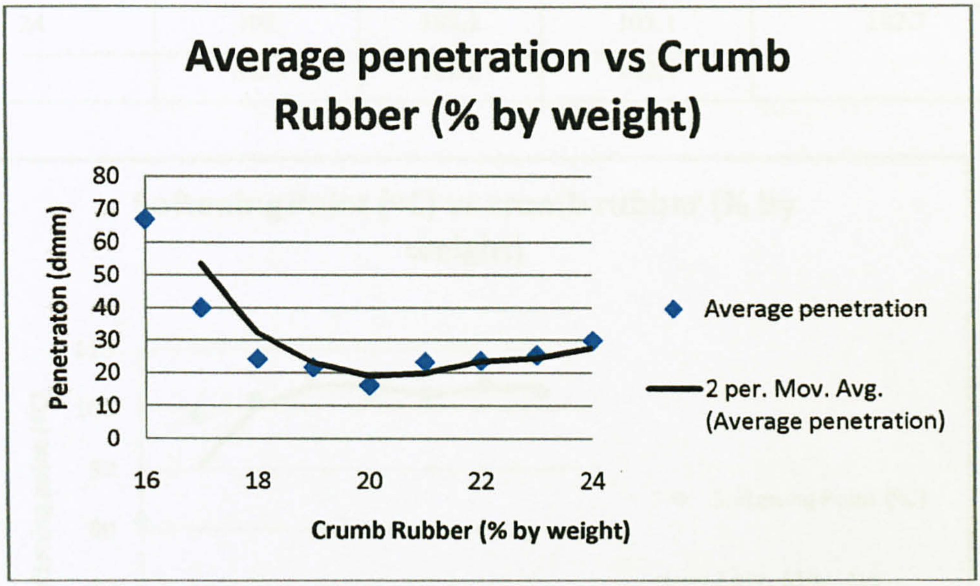

Figure 4.1: Penetration vs Crumb Rubber (% by weight)

Table 4.2: Ring and Ball test results

SOFTENING POINT TEST				
Crumb rubber percentage	Ball 1 (°C)	Ball 2 (°C)	Mean(°C)	Average(°C)
17	84.6	84	84.3	81.45
	79	78.2	78.6	
18	99	98.9	98.95	98.75
	98.9	98	98.5	
19	101.2	101.9	101.6	101.75
	102.1	101.6	101.9	
20	105.7	106	105.9	105.85
	106.2	105.3	105.8	
21	102	102	102	102.15
	102	102.5	102.3	
22	102.0	102.8	102.4	102.6
	102.8	102.8	102.8	
23	104	104.3	104.2	104.3
	104.4	104.4	104.4	
24	103	103.2	103.1	102.7
	102.3	102.3	102.3	

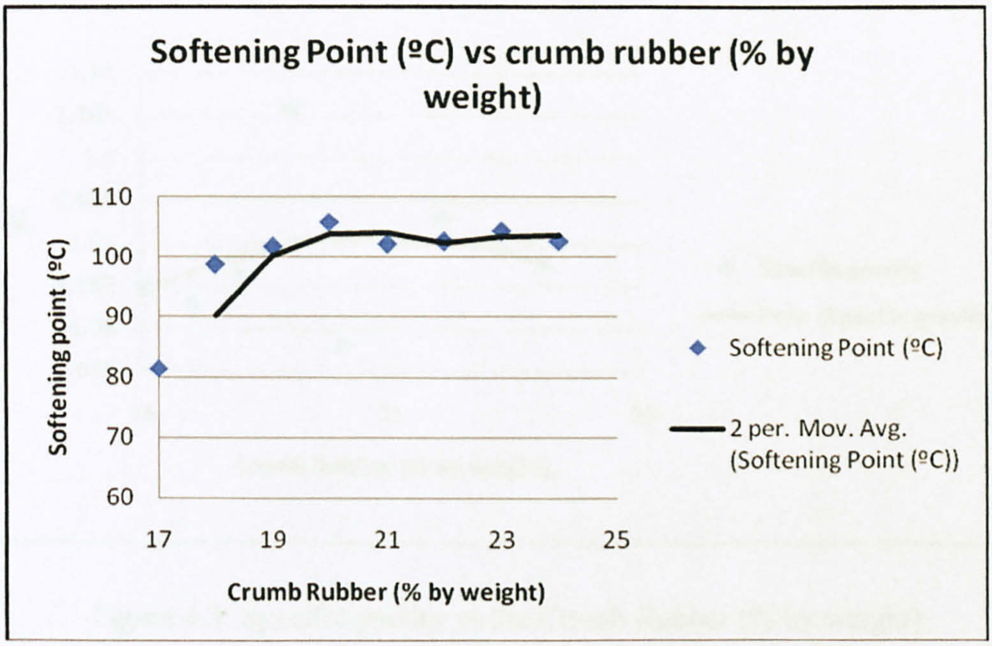

Fig 4.2 :Softening point of the binder Versus Crumb Rubber (% by weight)

Table 4.3 : Results of the specific gravity determination

Percentage of CR (%)	Specific gravity
16	1.085
17	1.083
18	1.086
19	1.106
20	1.078
21	1.09
22	1.093
23	1.09
24	1.0875

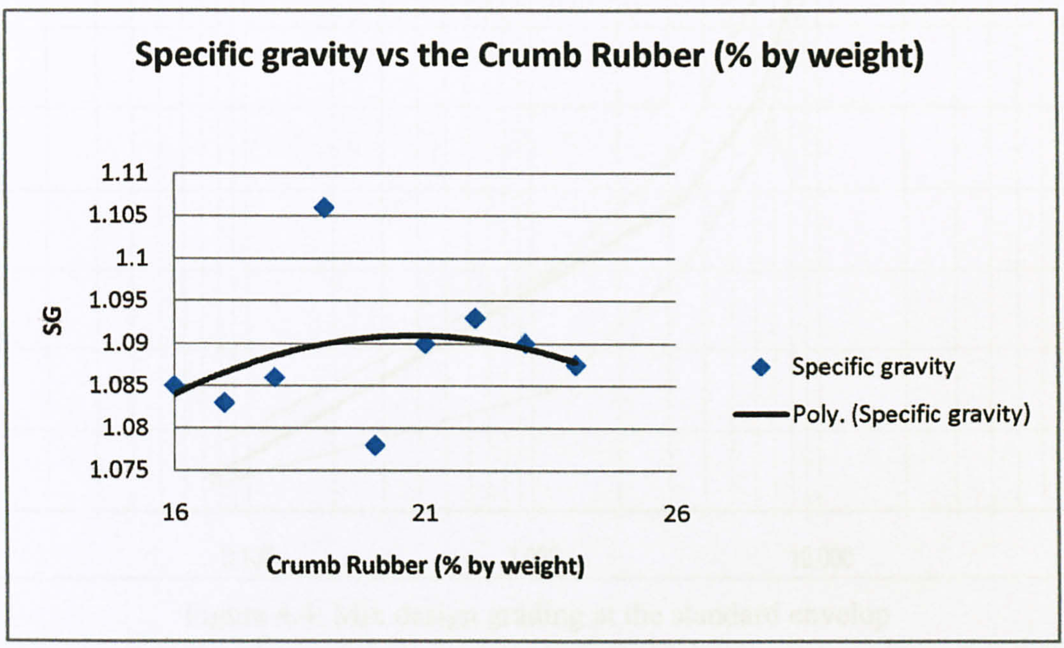

Figure 4.3: Specific gravity vs the Crumb Rubber (% by weight)

Table4.4: Percentage passing and the Mix gradation

Seive size	Coarse	Fine	Filler	TOTAL	Specifications	
20.000	100.0	100	100	100.00	Lower	Upper
14.000	99.1	100	100	100.00	100	100
10.000	66.5	100	100	99.34	95	100
6.300	33.6	100.0	100	74.57	70	90
3.350	16.6	99.9	100	51.51	45	65
1.180	9.0	90.7	100	38.56	30	45
0.075	0.8	1.0	80	29.01	15	30
				4.00	3	8

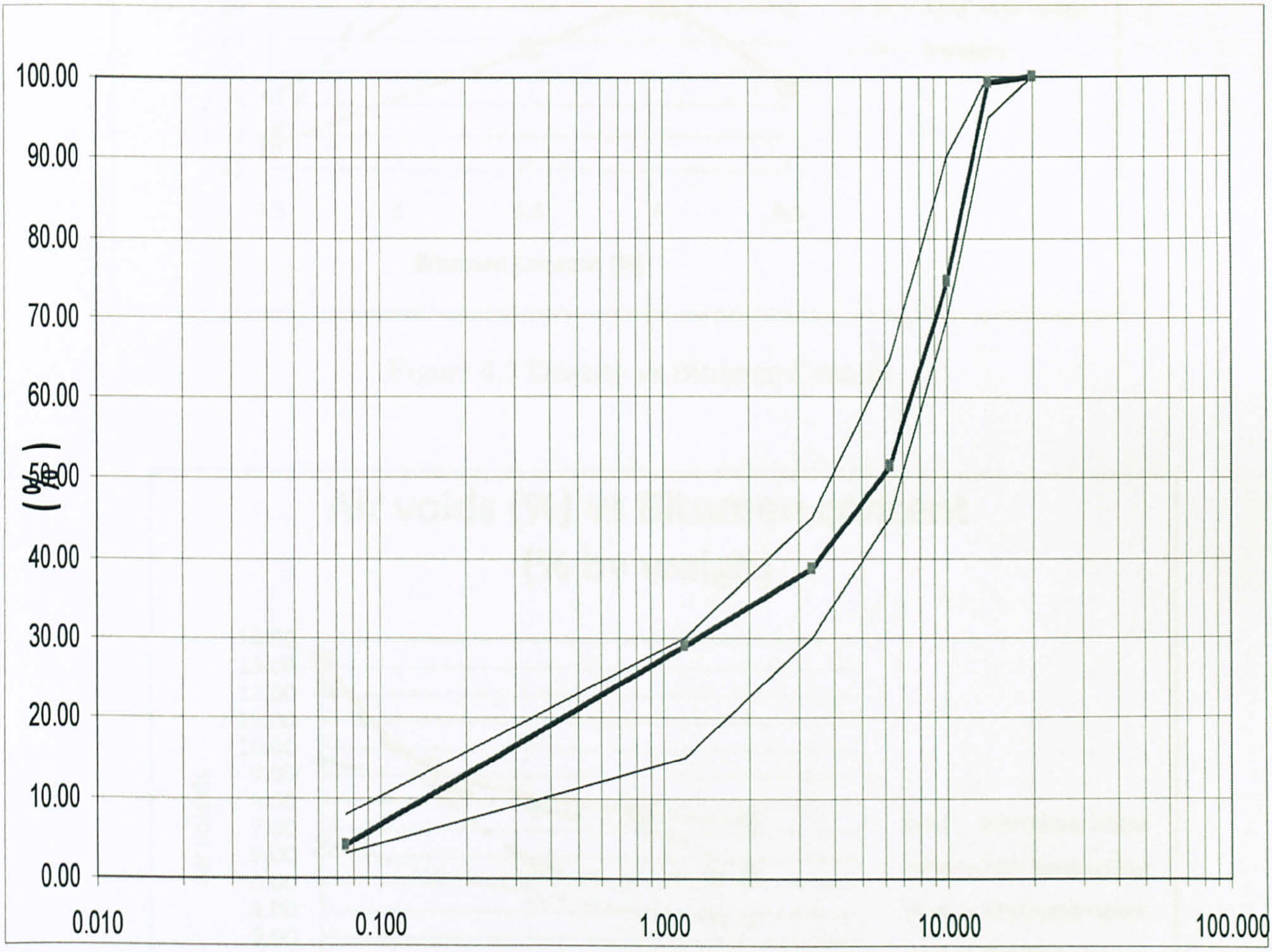

Figure 4.4: Mix design grading at the standard envelop

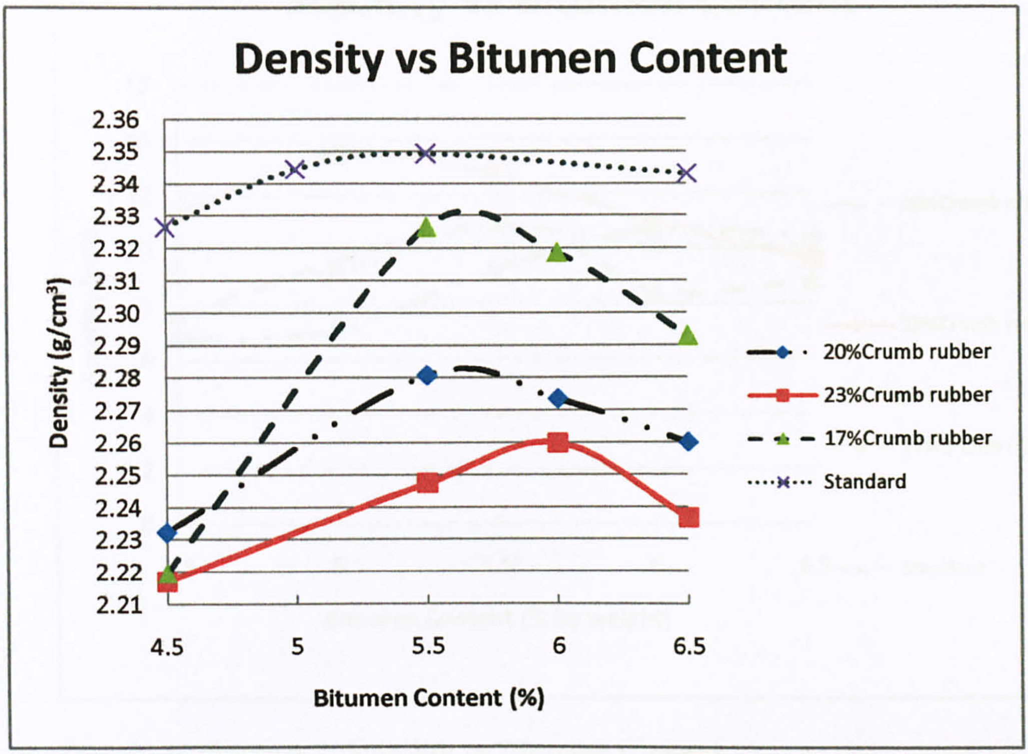

Figure 4.5 Density vs Bitumen Content

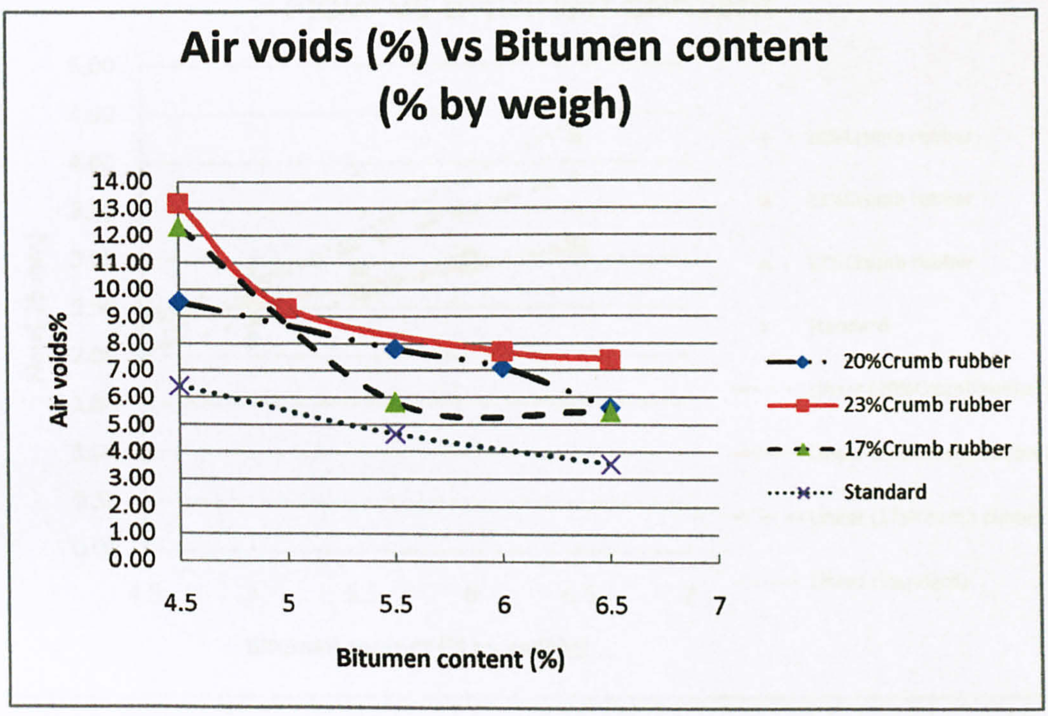

Figure 4.6: Air voids vs Bitumen content

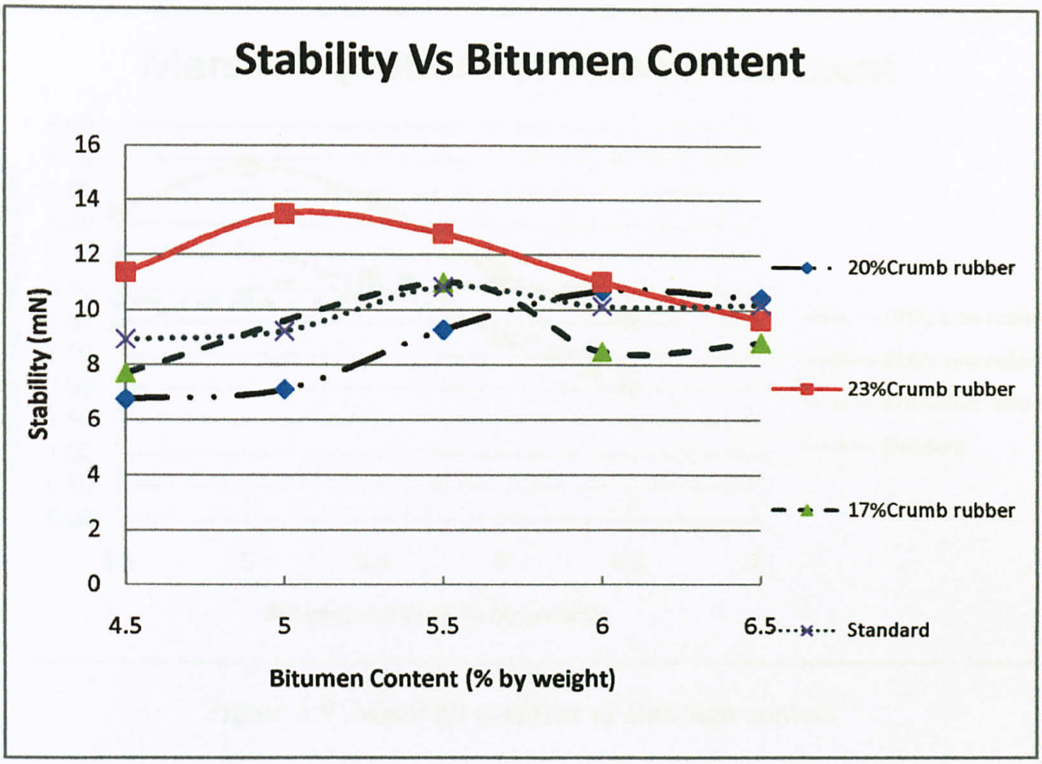

Figure 4.7: Stability vs Bitumen Content

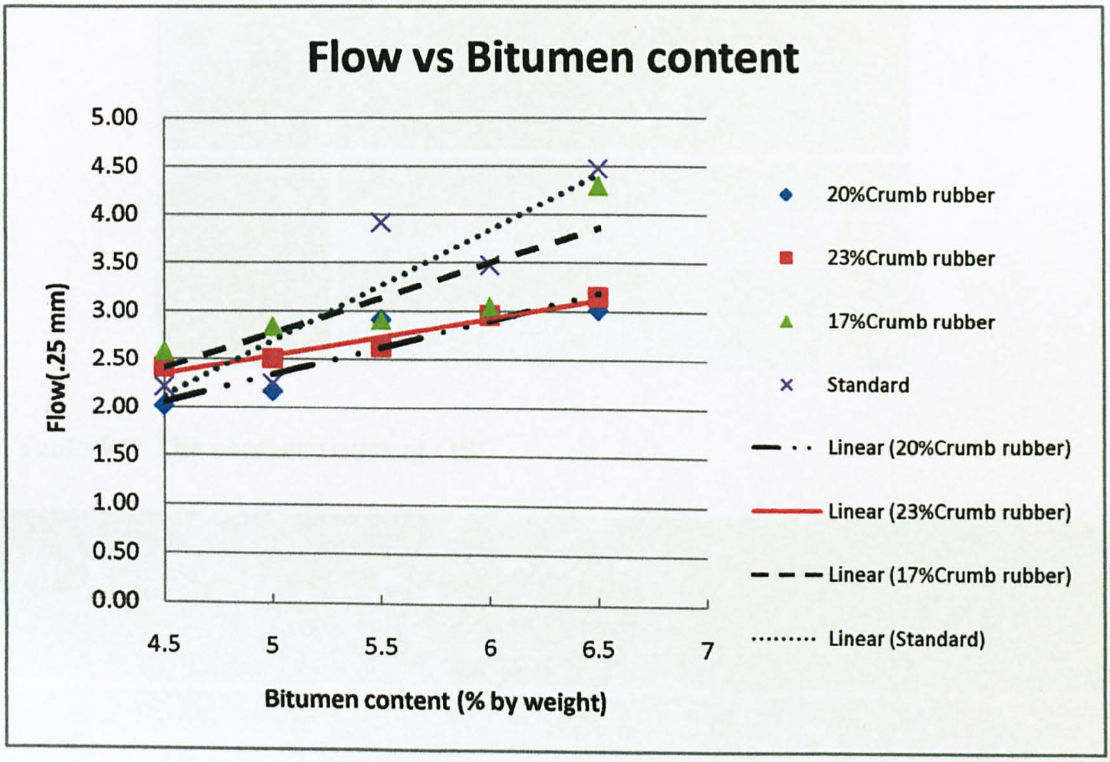

Figure 4.8: Flow vs Bitumen content

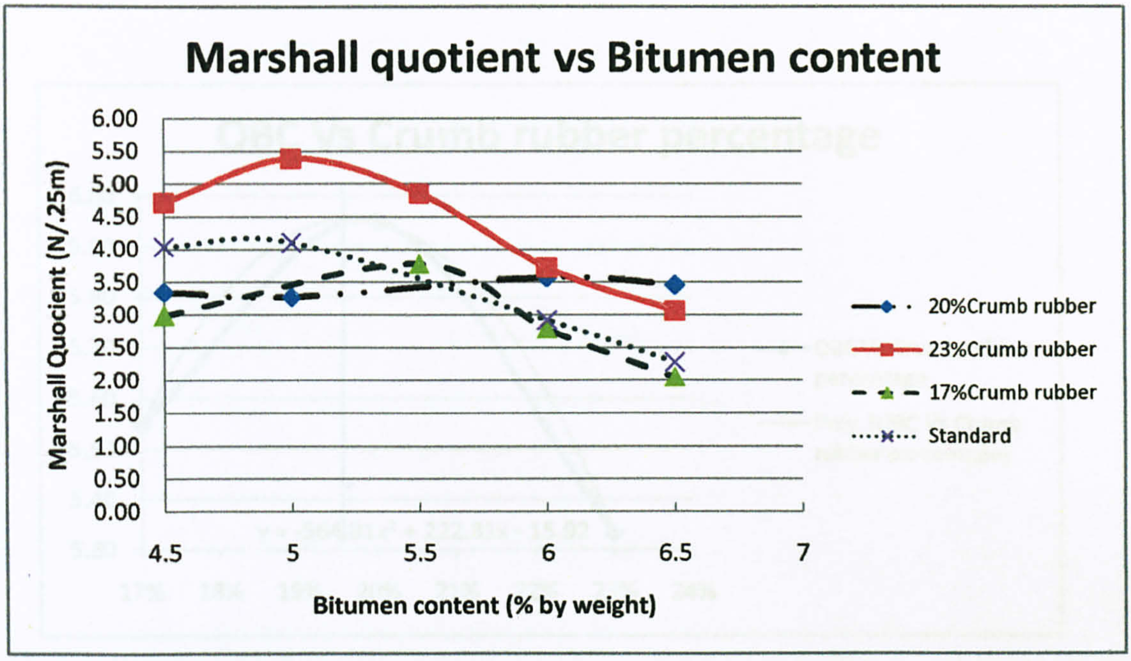

Figure 4.9: Marshall quotient vs Bitumen content

Table 4.5: The OBC determination

Content of rubber in the bituminous mix	Density (g/cm^3)	Stability(mN)	Marshall Quocient(N/.25m)	OBC (%)
0%	5.25	5.5	4.8	**5.2**
17%	5.65	5.5	5.5	**5.6**
20%	5.65	6.0	6.2	**6.0**
23%	6.0	5.0	5.0	**5.3**

Table 4.6: The characteristics at OBC

Content of rubber in the bituminous mix	Calculated OBC (%)	Density (g/cm^3)	Stability (mN)	Flow (x0.25 mm)	Marshal Quotient (N/.25m)	VMA (%)	Air Void (%)	Air Voids filled with bitumen (%)
0%	5.2	2.35	10	2.9	4	16.5	5.2	66.5
17%	5.6	2.33	11	3.4	3.7	17.25	5.3	66
20%	6.0	2.27	11	3.0	3.51	19.3	7	65
23%	5.3	2.24	13.5	2.7	5.15	19.4	8.8	52

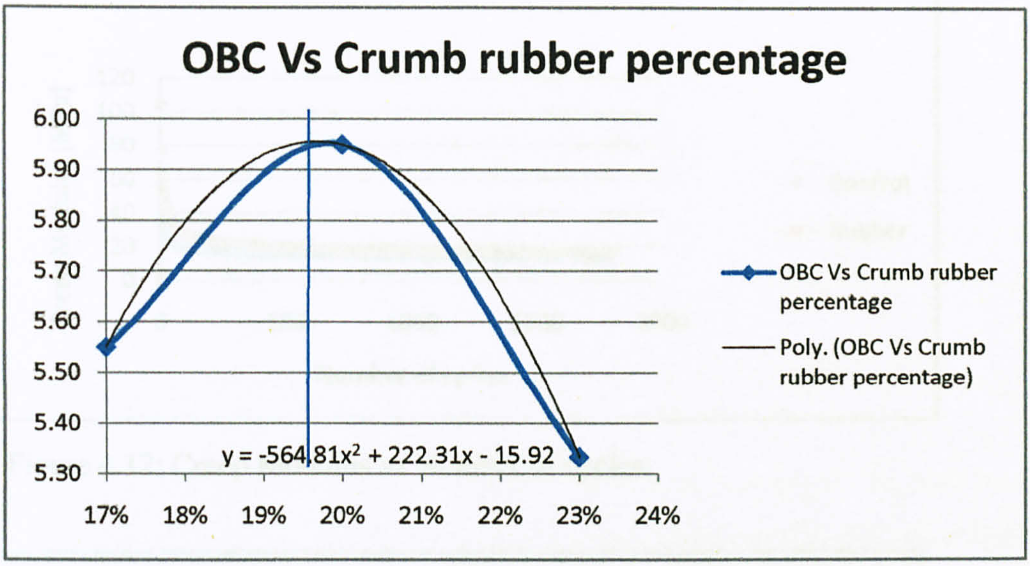

Figure 4.10: Optimum Rubber Content determination graph

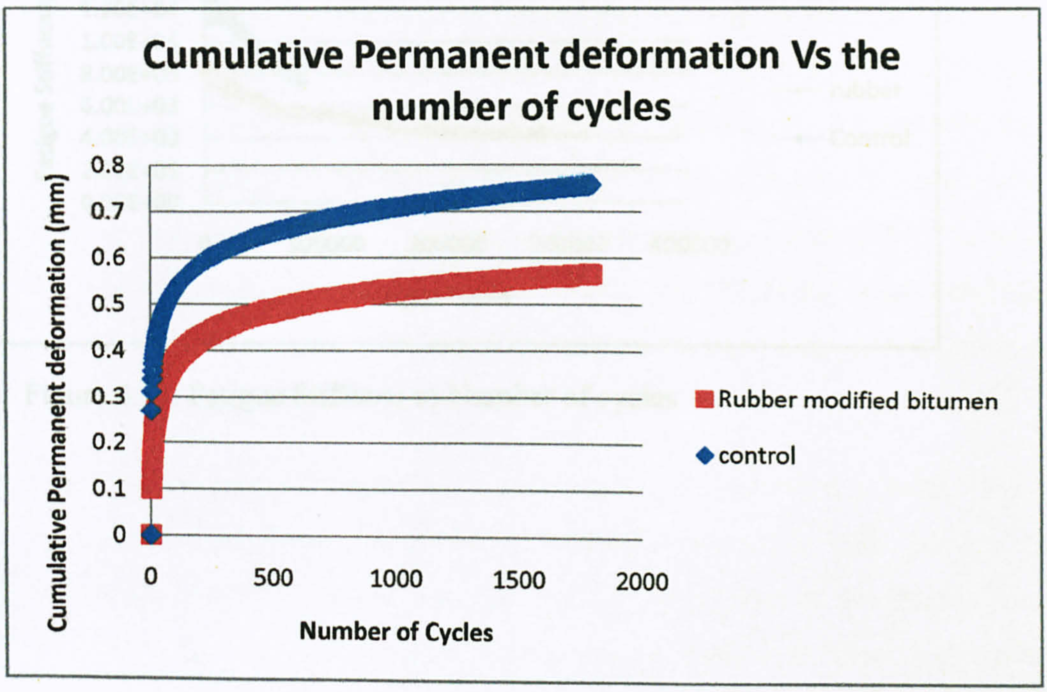

Figure 4.11: Cumulative Permanent deformation Vs number of cycles

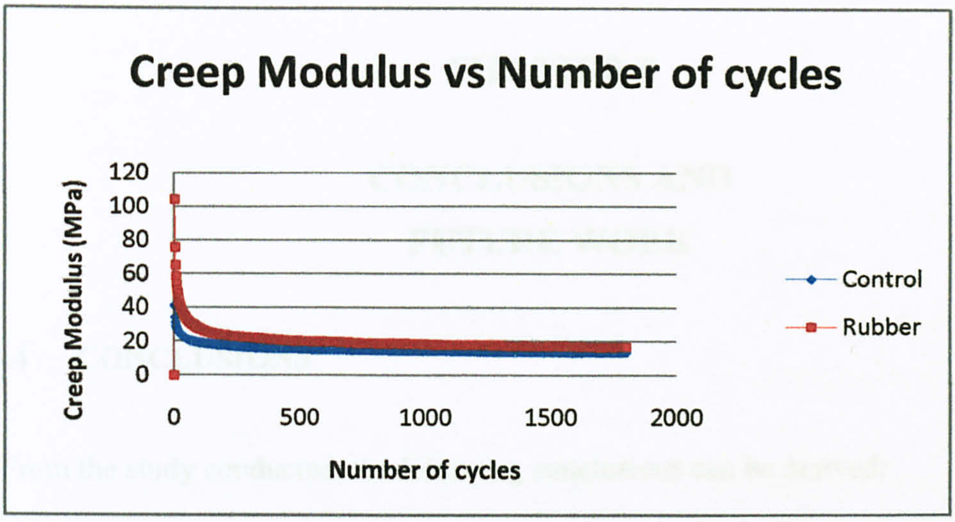

Figure 4.12: Creep Modulus vs Number of cycles

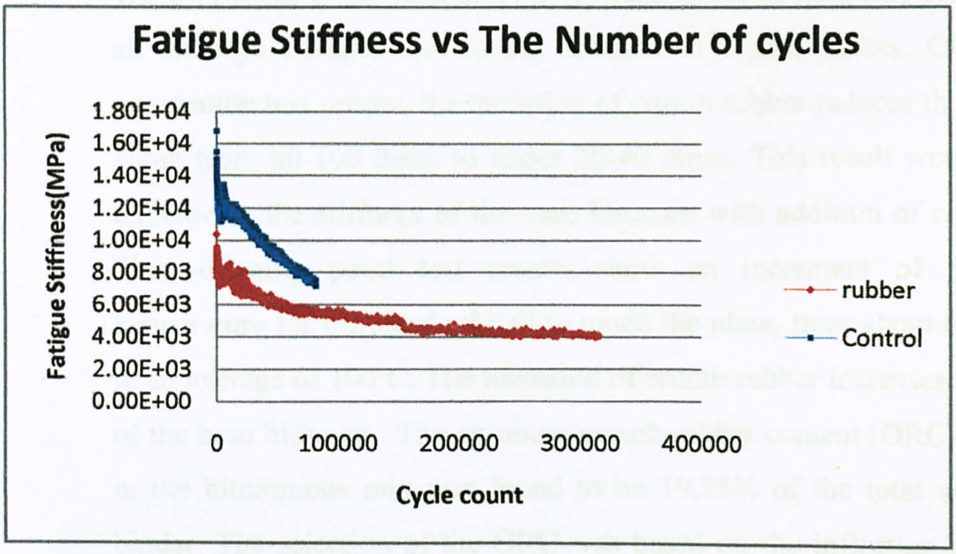

Figure 4.13: Fatigue Stiffness vs Number of cycles

CHAPTER 5

CONCLUSIONS AND FUTURE WORK

3.4 CONCLUSIONS

From the study conducted, the following conclusions can be derived:

1. The incorporation of crumb rubber affects the properties of the base bitumen. The properties of the resulting binder such as penetration and softening point all undergo changes due to the addition of crumb rubber. Observing the penetration test results, the inclusion of crumb rubber reduces the penetration value from 80-100 dmm to about 20-40 dmm. This result would imply an increase in the stiffness of the base bitumen with addition of crumb rubber. The softening point test results show an increment of the required temperature for the standard ball to touch the plate, from about 65ºC to close to an average of 100ºC. The inclusion of crumb rubber increases the viscosity of the base bitumen. The optimum crumb rubber content (ORC) to be added in the bituminous mix was found to be 19.75% of the total weight of the binder. The selection of the ORC was based on the inflection points of the softening point, penetration and density tests.

2. The aggregate selection was done in accordance with the JKR recommendations and the British Standard 594 part 1: 1985. For the study a well graded gradation was followed in accordance to the British Standard 594. The aggregate characterization tests namely Los Angeles abrasion test, elongation and flakiness index were conducted in accordance to JKR standards. The coarse aggregates, fine aggregates and filler used was granite, river sand and Ordinary Portland Cement respectively. The base bitumen selected for the study was the 80/100 bitumen. The crumb rubber used was obtained on used tyres from passenger cars and trucks.

3. From the Marshall test results the properties of the bituminous mixtures were determined. Five properties were analyzed namely, density, VMA, stability, flow and the Marshal Quotient (stiffness). From the results the following conclusions can be drawn:

   - The density of the binder is reduced with the addition of crumb rubber. Higher the proportion of rubber results in a lower density.

   - The proportion of voids increases with addition of crumb rubber; this is justified by a courser binder resulting from the partial digestion of the crumb rubber in the reaction with bitumen.

   - The stability load is slightly increased with the incorporation of crumb rubber resulting from the formation of a stronger binder proving the formation of the binding gel.

   - The stiffness, represented by the Marshall Quotient results, increases with the addition of crumb rubber. However, at the optimum rubber content the stiffness of the rubber modified bituminous mixture is lower compared with the conventional bituminous mixture.

4. The addition of crumb rubber increases the optimum binder content (OBC), however it reduced the amount of base bitumen to be used. From the Marshall results, the standard bituminous mixture had an OBC of 5.2% and the modified bituminous mixture had an OBC of 5.95%. From the characteristics tests, the optimum rubber content is 19.75% of the binder content. Using basic mathematical interactions it was determined that the modified binder will only require 4.77% of the total weight as the base bitumen.

5. The performance tests namely dynamic creep stiffness and beam fatigue tests prove that the addition of crumb rubber improves the performance of the bituminous mixture. Based on the dynamic creep stiffness test results, it is observed that the creep resistance of the rubber modified asphalt is 17.1 MPa and the conventional asphalt is 13.8 MPa. Implying that the dynamic load resistance of the rubber modified asphalt is higher compared with the conventional asphalt. It can also be observed, from the same results, that the

deformation resistance is higher for the rubber bitumen asphalt compared with the conventional asphalt.

6. Based on the beam fatigue test results, it can be observed that the initial stiffness of the conventional asphalt is higher compared to the rubber modified asphalt. These results prove that the rubber modified asphalt is more elastic, thus it is less thermal susceptible compared with the control. Albeit the fact that the stiffness is higher for the conventional asphalt, due to the added elastic capabilities, the rubber modified asphalt takes a longer span of time to reach the terminal stiffness. From the test results the conventional asphalt reaches the terminal stiffness in 4.30 hours whereas the modified rubber bitumen reaches the terminal stiffness in 17.30 hours.

3.5 FUTURE WORK

1. Improve the workability of the bituminous mixture with rubber-bitumen, by adding extender oil; It is reported that the addition of an extender oil could improve the workability of the asphalt mixture without affecting much the characteristics of the binder.

2. Compare the effects of the shear on the mixture. From all the specifications it was imposed that the shear should be of at least 3000 r.p.m, this study was conducted at a shear of 637 r.p.m. The questions which should be answered are: How much is the shear affect? What is the performance variance with different shear speed? And what if we include pressure into the equation?

3. Compare the difference, in terms of engineering properties, between the wet and the dry method at various conditions. The dry method is far cheaper compared with the wet method thus optimizing a mixture which could have the engineering advantages would revolutionize the industry.

4. Further reduce the construction cost by using cheaper fillers, such as quarry dust, rice hush and more.

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