A STUDY ON THE BEHAVIOUR OF BITUMINOUS MIXTURE WITH DIFFERENT FILLERS

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A Study on the Behaviour of Bituminous Mixture with Different Fillers

by

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved by,

____
(Assoc Professor Dr Ibrahim Kamaruddin)

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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.

SUHAIMI BIN MAHASAN

ABSTRACT

During the last two decades the rise in road traffic loads parallel to an insufficient degree of maintenance has resulted in accelerated weakening of road structures throughout the world. To minimize or possibly eliminate this problem, several types of measures may be considered, e.g. improvement in road design, more optional use of new materials and more effective construction methods have been proposed. The properties of materials in all layers of the road structures i.e. surface course, base course and subbase course play great importance in the life of the road. Several factors influence the performance of flexible courses, e.g. the properties of the component materials (binder, aggregate and filler) as well as the proportion of these components in the mix. Over the years, many different types of materials have been proposed as fillers in bituminous mixtures. The purpose of using special fillers in an asphalt pavement is to achieve better road performance in one way or another. In this study, asphalt concrete specimens with 3 different types of fillers i.e. fly ash, lime and crumb tire rubber were studied by incorporating them in the bituminous mixture at the optimum bitumen content and were analyzed in the laboratory. This study found that there were improvement in the physical and mechanical properties of bituminous mixtures as a result of incorporating the different fillers.

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Last, but certainly not least, I would like to apologize if any party was inadvertently excluded from being mentioned above and would like to thank all parties that were involved in making this project a success.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Bitumen is defined as a tarlike mixture of hydrocarbons derived from petroleum naturally or by distillation, and used for road surfacing and roofing. Bitumen is manufactured from crude oil. It is generally agreed that crude oil originates from the remains of marine organisms and vegetable matter deposited with mud and fragments of rock on the ocean bed [1].

The bituminous mixtures are a combination of bituminous materials as binders, properly graded aggregates and filler materials is sometimes added to bituminous mixtures. Filler materials consist of very fine, inert mineral matter that is added to the bituminous mixture. Usually in highway construction, some constructions add filler material in bituminous mixture but not all highways were building up by combination of the filler material. When the filler materials is added to a bituminous paving mixture, there are some questions arise and need to be answered which are:

- What improvement is needed?
- What material component will provide the improvement?

This project is carrying out to determine the improvement characteristic of bituminous mixtures when adding the filler material.

1.2 Problem Statement

The increase in road traffic loads during the last two decades in combination with an insufficient degree of maintenance has caused an accelerated deterioration of road structures in many countries. Even increasing numbers of commercial vehicles with super single tires and increase axle loads have taken their toll and it is clear that this trend will continue in the future. The performance of asphaltic bituminous mixtures in all kinds of environment gives rise to different conditions. They are brittle and hard in cold environment and soft in hot environment giving rise to their susceptibility to deformation.

One of the most common mode of failures in bituminous pavement is permanent deformation (rutting) especially in the wheel track (Figure 1). Rutting is described as the surface depression in the wheelpath after millions of application of the wheel load. When this occurs, pavement uplift (shearing) also may occur alongside of the rut. Increased traffic volume, heavy loaded vehicles and the high ambient temperatures in countries like Malaysia and Indonesia have resulted in rutting (deformation) in bituminous pavement being even more pronounced [4].

Figure 1: Rutting of pavement structure

To assist the highway engineer to meet the growing challenge of up keeping high quality pavements, there now exists a wide range of proprietary asphalts made with modified bitumen containing different type of fillers. These products have been proven in service to enhance the properties of the bitumen and bituminous mixtures as certified by the number of journal papers published on this subject.

1.3 Objective and Scope of Study

This study intends to look into the properties of bituminous mixtures incorporating different types of fillers. The engineering properties of the base mix and modified mixtures were compared and studies. The engineering properties of these mixtures such as their stability, flow, voids and voids in mineral aggregate (VMA) were determined.

The study started with the physical properties of the materials used. This includes tests on bitumen and aggregates used.

The performance tests on the resulting bituminous mixtures at their optimum bitumen content were conduct of interest were to test relating to deformation (rutting) and fatigue (cracking). The wheel tracking test and beam fatigue test were employed for these performance behavior of the mixtures.

CHAPTER 2
LITERATURE REVIEW AND THEORY

2.1 Overview of Fillers

For the additives to be effective and for its use to be both practicable and economical, it must [1]:

- be readily available
- resist degradation at asphalt mixing temperatures
- blend with the bitumen
- improve resistance to flow at high road temperatures without making the bitumen too viscous at mixing and laying temperatures or too stiff or brittle at low road temperatures
- be cost effective.

The fillers, when blended with bitumen, should:

- maintain its premium properties during storage, application and in service
- be capable of being processed by conventional equipment
- be physically and chemically stable during storage, application and in service
- achieve a coating or spraying viscosity at normal application temperatures

The physical characteristic required for the fillers in bituminous mixtures are defined in AASHTO M17 and are shown in Table 1[5]:

Table 2.1 AASHTO M17 specification requirements for fillers use in bituminous mixtures.

Particle Sizing		Organic Impurities	Plasticity Index
Sieve Size	Percent Passing		
0.006 mm (No. 30)	100	Mineral filler must be free from any organic impurities	Mineral filler must have plasticity index not greater than 4
0.003 mm (No. 50)	95-100		
0.075 mm (No. 200)	70-100		

In this study, three different types of material were used as fillers in the bituminous mix. These include fly ash, hydrated lime and crumb tire rubber.

2.1.1 Fly Ash

Fly ash is a by-product from coal combustion plants and it contains 5% calcium, 55 % silica, and 11% alumina [6]. The remaining chemicals in the fly ash are ferric and magnesium oxides. Fly ash was observed to be a good filler in bituminous mixture because of the unique spherical shape, particle size distribution; typically ranging in size between 10 and 100 micron (Figure 2) and because of its pozzolanic characteristics. Pozzolans are siliceous and aluminious materials, which were characterized as finely divided form and react with calcium hydroxide in the presence of water at ordinary temperature to produce cementitious compounds. Fly ash is also non-water wettable material which are known to have hydrophobic characteristic. This characteristic is beneficial since it can reduce the potential for the asphalt mixture agaisnt stripping. Based on its chemical composition, fly ash can be classified either as Class C or Class F ash.

Class C ashes consists of calcium alumino-sulfate glass, as well as quartz, tricalcium aluminate and free lime (CaO). This type of ashes are also often referred to as high calcium fly ash because it typically contains more than 20 percent CaO.

Class F ashes nevertheless consist of an alumino-silicate glass, with quartz, mullite and magnetite also present. Class F are also called low calcium fly ash as they have less than 10 percent CaO.

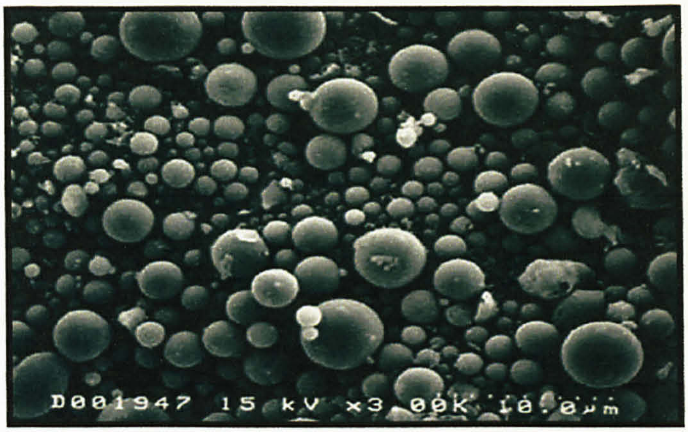


Figure 2: Fly ash particles at 2,000x magnification.

Class C fly ash and Class F-lime product blends can be used in numerous applications and have common benefits in highway construction. These include:

- increase in the stiffness of the asphalt matrix
- improvement in rutting resistance
- increase in mix durability
- provide similar performance using less material by weight
- may afford a lower cost than other mineral fillers
- To enhance resistance to stripping due to hydrophobic properties of the fly ash

Figure 3 shows a pavement core indicating stripping occurred at the bottom of the pavement section.

Figure 3: Small pavement core showing stripping at the bottom of the pavement section

Below are the properties of the fly ash that are likely to be useful generally in engineering and specifically in this study:

- *Gradation.* Fly ashes typically fall within a size range between 60 to 90 percent passing the 75 μm [6].
- *Fineness.* Fly ash has 40 to 70 percent passing the 20 μm sieve and blends well with bitumen to form a mortar.
- *Specific Gravity.* Typically most fly ash having specific gravity of 2.0 to 2.6.

For the incorporation of the fly ash with the bituminous mixture, the percentage of fly ash is the lowest percentage that will enable the mix to satisfy all the required design criteria. Inclusion of high calcium fly ash in the bituminous mixture may improve asphalt stripping (Figure 3) with many aggregates. All of these will be justified in later stage of the study when the laboratory work takes place.

2.1.2 Hydrated Lime

Hydrated lime, Ca $(OH)_2$ is produced from the heating of limestone or calcium carbonate to remove carbon dioxide. The residual calcium oxides are also known as quicklime. It is very active chemical. A controlled amount of water is added to form calcium hydroxide to improve the handling characteristic of the quicklime. This combination of quicklime and water is usually referred to as hydrated lime. Reaction below shows the chemical reaction between the quicklime (CaO) and water (H_2O) resulting in hydrated lime Ca $(OH)_2$ and generates heat.

Calcium Oxide + Water = Calcium Hydroxide + Heat

$\{CaO\} + \{H_2O\} = \{Ca(OH)_2\}$

Addition of lime constituent to the aggregate normally carries an intention to improve the bond between the aggregate and bitumen. As mentioned in the paragraph above, hydrated lime is a combination of lime with water. In the presence of water, it provides stronger bond affinity between the aggregate and bitumen rather than ordinary mixtures. From previous studies, addition of a modest amount of commercial hydrated lime (usually ½ to 2 percent by weight) are one of the most recognized ways to improve the anti-stripping characteristics of an asphalt paving mixture.

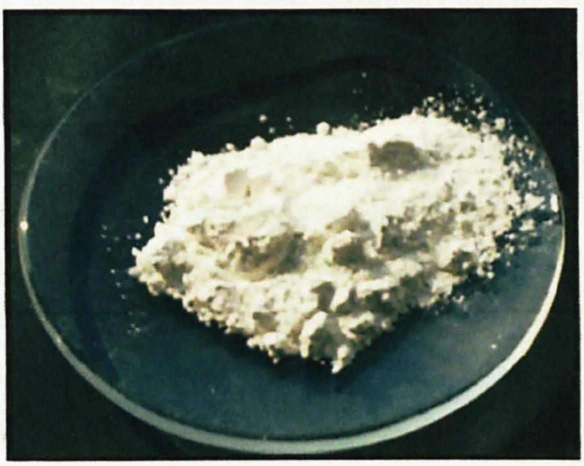


Figure 4: Hydrated Lime

Below are the chemical properties of the hydrated lime [7]:

- **IUPAC name.* Calcium hydroxide
- ***CAS number.*[1305-62-0]
- *Molecular formula.* $Ca(OH)_2$
- *Molar mass.* 74.093 g/mol
- *Grading.* 50% less than 0.005mm
- *Appearance.* It appears in soft white powder or colorless liquid (Figure 4)
- *Density.* 2.211 g/cm^3, solid
- *Melting point.* 512°C
- *Solubility in water.* 0.185 g/100 cm^3 and having solubility equilibrium, $K_{sp} = 7.9 \times 10^{-6}$
- ****Basicity.*-2.37 and having pH = 12.0-12.5

Note: * International Union of Pure and Applied Chemistry (IUPAC)

** CAS number is a unique numerical identifiers for chemical compounds, polymers, biological sequences, mixtures and alloys

*** Basicity is referred to an acid dissociation constant

Hydrated lime has the ability to control water sensitivity and its well-accepted ability as an antistrip to inhibit moisture damage. Currently, hydrated lime also was found out to generate other effects in bituminous mixture. As to be specific, lime acts as an active filler, anti-oxidant, and as additive that reacts fines in Hot Mix Asphalt (HMA). These mechanisms create several benefits for pavements [8]:

1. Hydrated lime acts as mineral filler, stiffening the asphalt binder and HMA.
2. It improves resistance to fracture growth (i.e., it improves fracture toughness) at low temperatures.
3. It favorably alters oxidation kinetics and interacts with products of oxidation to reduce their deleterious effects.
4. It alters the plastic properties of clay fines to improve moisture stability and durability.

5. It reduces the potential of asphalt to deform at high temperatures, especially during its early life when it is most susceptible to rutting.

2.1.3 Crumb Tire Rubber

The use of crumb tire rubber as a filler in various type of bituminous construction not only solves a waste disposal problem and offers the benefit of resource recovery; it is also of interest to the paving industry because of the additional elasticity imparted to the binder and pavement system. Performance results from the literature review show that adding tire rubber to the bituminous mixture can increase fatigue and reduce rutting. Crumb tire rubber is usually obtained by shredding and grinding (milling) the tire rubber at or above ordinary room temperature. This process produce a sponge-like surface on the granulated rubber crumbs which have considerably greater surface area for a given size particle than do ground rubber particles. Increase surface area increases the reaction rate with the bitumen [9].

Figure 5: Crumb Tire Rubber

A blend of crumb tire rubber with bitumen has been used as a binder at elevated temperature in diverse types of bituminous construction, rehabilitation and maintenance. This blend is called "asphalt-rubber" and normally consists of 18 to 26 percent ground tire rubber by total weight of the blend.

Crumb rubber has been used for the following applications in road constructions [9]:

1. Asphalt-rubber seal coat (ARSC)
2. Asphalt-rubber stress absorbing membrane (SAM)
3. Asphalt-rubber stress absorbing membrane interlayer (SAMI)
4. Asphalt-rubber concrete (ARC)
5. Asphalt concrete rubber filled (ACRF) or rubber-modified asphalt hot mix
6. Asphalt-rubber crack sealer

Only ACRF uses a simple mixture of asphalt cement, crumb tire rubber particles (as an additives) and aggregates [9].

From this study, the bituminous mixture containing crumb tire rubber must meet all relevant performance related specifications. Should any material fail to meet the required specifications, it will be rejected.

Below are some concerns regarding the usage of crumb tire rubber in bituminous mixtures:

1. feasibility and economics of the use of rubber in highway construction applications,
2. availability of the crumb tire rubber and its cost.

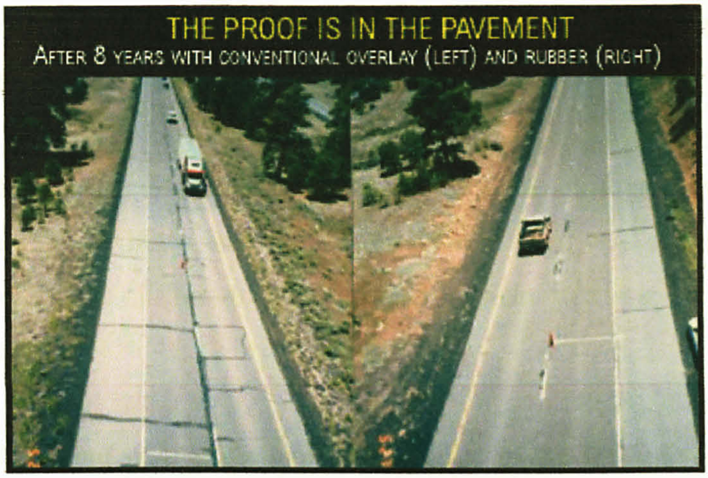


Figure 6: Differences between unmodified asphalt pavements and rubber modified asphalt pavements

Asphalt rubber pavements may last up to twice as long as conventional materials before needing maintenance or replacement. Another advantage in the use of rubber in bitumen is that some construction can be as low as half the thickness of conventional pavement, thus saving on material and installation costs as well as construction time. Numerous case studies have proven again and again that using an asphalt-rubber binder in a pavement provides better resistance to cracking and fatigue which is caused by heavy traffic. This leads to lower operating costs [10].

2.2 The Effect of Filler as Modifier in Binder on Asphalt Concrete Properties

Aschuri I. (2007) work on the behavior of asphalt concrete mix containing fly ash and hydrated lime in binder has been conducted by a number of analysts whom is Aschuri I. (2007). The additives as modifier were prepared with certain percentages by weight of bitumen used. Penetration test at various temperatures and softening point test has been used to evaluate the bitumen filler binder properties. The tests revealed that the penetration values of modified bitumen were found to be lower than the unmodified bitumen. Likewise the softening point values showed it to be increasing in value when compared to that unmodified sample. Aggregate used in his study was crushed basalt and the modifiers used were Fly Ash and Hydrated Lime having particle density of 2.35 gr/cm^3, 2.24 g/cm^3 respectively.

From the Marshall tests, it was found that the modified bitumen were better than unmodified in term of stability, unit weight, air void in mix, void in mineral aggregate and stripping resistance. Filler are included in asphalt mixture to provide greater stability and strength.

Aschuri I. (2007) found in his work the Penetration Index (PI) of modified bitumen using fly ash and hydrated lime increased to an optimum value and later decreased. In addition of these modifiers also caused improvement in temperature susceptibility.

In his work, the results of Marshall tests gave us the relationship between modifier content and properties of mix such as Marshall Stability, Flow, Quotient, density VMA and VIM. The addition of Fly Ash and Hydrated Lime increased the Marshall stability and stiffness of the material. It also results in an increase in the Voids in Mix Value (VIM) and Void in Mineral Aggregate (VMA), and reduced moisture susceptibility. In his study, the modifiers also reduced the density of the asphaltic concrete.

In conclusion, the performance of asphalt concrete mixes prepared using fly ash and hydrated lime as modifier were better than the original bitumen mixes [11].

The work presently undertaken uses similar modifier as that used by Aschuri I. (2007) namely fly ash and hydrated lime. In this sense, the results obtained from this study can be compared to those obtained by Aschuri I. (2007).

2.3 Rubber Modified Bitumen

Yousefi A. A. (2002) has initiated a study of bitumen modification with rubber. Four types of rubbers were used in his research; polybutadiene, two others were styrene-butadiene random block copolymers (SBR 1502 and SBR 1712) and the fourth type was natural rubber (SMR 20). 60/70 penetration grade bitumen were used.

For the procedures, these four types of rubbers were cut into small pieces prior to mixing with bitumen. The mixer was heated up to 170°C prior to the mixing. Speed of 7000rpm was applied at the beginning of the mixing and during the first 5 minutes of mixing the rubber pieces were added. For the next 30 minutes, 12000rpm speed was applied. Samples from the mixer were taken for penetration and ring & ball tests.

From the results, for the 60/70 penetration grade bitumen and its blend are summarized in Table below.

Table 2.2: Different properties of 60/70-bitumen and its modified forms.

Sample	Penetration at 25°C (0.1mm)	Softening point (°C)	Frass breaking point (°C)	Penetration index	Performance grade
Base 60/70 bitumen	64	49.5	-12	-0.754	64-22
Control bitumen	37	63	-9	0.909	85-16
5%PBR1220	50	69.5	-8	2.765	88-16
5%SBR1502	30	63	-12	0.526	82-22
5%SBR1712	34	65	-7	1.111	82-10
%SMR 20	33	68	*	1.538	88-?

(*) the test was impossible to do.

Polybutadiene forms a continuous phase in bitumen and improves the performance of bitumen at high temperature via increasing its consistency. SBR1712 improves the high temperature properties and make bitumen more brittle at low temperature. SBR1502 recovers all properties of the base bitumen with exception of the increasing its performance at high temperatures. Natural rubber stiffens bitumen, resulting in better performance at high temperatures and it makes bitumen brittle at low temperatures. The blends of softer bitumen (60/70) with these rubbers are of higher penetration and softening point with respect to those of harder bitumen [2].

While Yousefi A. A. (2002) in his work used the crumb rubber into the bitumen (wet mix) to determine the properties of the resulting bituminous mix, the present work will partially substitute the filler used (OPC) with the crumb rubber. This is done on the basis of partial replacement by weight of the filler.

CHAPTER 3
METHODOLOGY/ PROJECT WORK

3.1 Project Methodology

The first step is to prepare a proper planning of the project. This includes producing a Gantt chart (see appendix A) that will be used throughout the project duration as guidance in term of time management. The second part is to collect all related journals as for case study and to further the understanding about this study. Then it will be following through by the selection of type of fillers that will be use for this study. After the discussion with the lab assistant, the critical factor in choosing the fillers is the availability of each of these fillers. The critical steps of this study are the laboratory work for the bituminous mixture design with addition of these fillers which specified below.

The basic testing methodology for bituminous mixture design as illustrated in Figure 7 starts with five preparatory steps [12]:

1. *Characterization* of the base components (binder, fillers and different aggregate fractions) and of the mixture composition (grading curve, proportions of the constituents including the binder).

   The material characterization involves undertaking the relevant standard tests for the material used. These include the Standard Penetration Test, Ring and Ball test (BS812: Part 1:1985) on the bitumen. Tests on aggregates conducted were the LA Abrasion Test (ASTM C 131), specific gravity test and etc. These tests will be explained in greater detail later.
2. *Definition of the design parameters* with respect to requirements (loading, climate, life cycle etc.) and pavement structure (including the position and function of the material in this structure) for a specific design job.

3. *Selection of the type of mixture,* such as asphalt concrete, stone mastic asphalt, open graded asphalt, overlays, etc. which is expected to have the best chance to meet the requirements formulated under step 2.
4. *Selection of test method as well as type and degree of compaction* suited to assess performance with respect to fatigue, permanent deformation, cracking, such as Marshall Stability Test, Softening Point Test, Force Ductility Test, Gradation or Sieve Analysis (for crumb tire rubber) and etc…
5. *Composition of the mixture for testing* based either on experience, theoretical considerations or on the results from previous mixture design iterations.

The next two steps concentrate on mixture design and performance prediction testing and consist of:

6. Manufacture of the *sample*.
7. Volumetric and mechanical *testing* including determination of sample composition (binder content, air voids) and testing of modulus, fatigue, permanent deformation, thermal cracking. Marshall Stability Test also need to be taken by using gyratory testing machine, mechanical mixer, oven, Marshall testing machine and etc. to determine the Marshall Stability, Marshall Flow and Marshall Stiffness. Standard Penetration Test also needs to be taken by using penetrometer to determine the modified bitumen penetration.
8. *Data* processing, collection and analysis with respect to:
    - Volumetric characteristics,
    - Mechanical characteristics,
    - Statistical assessment.

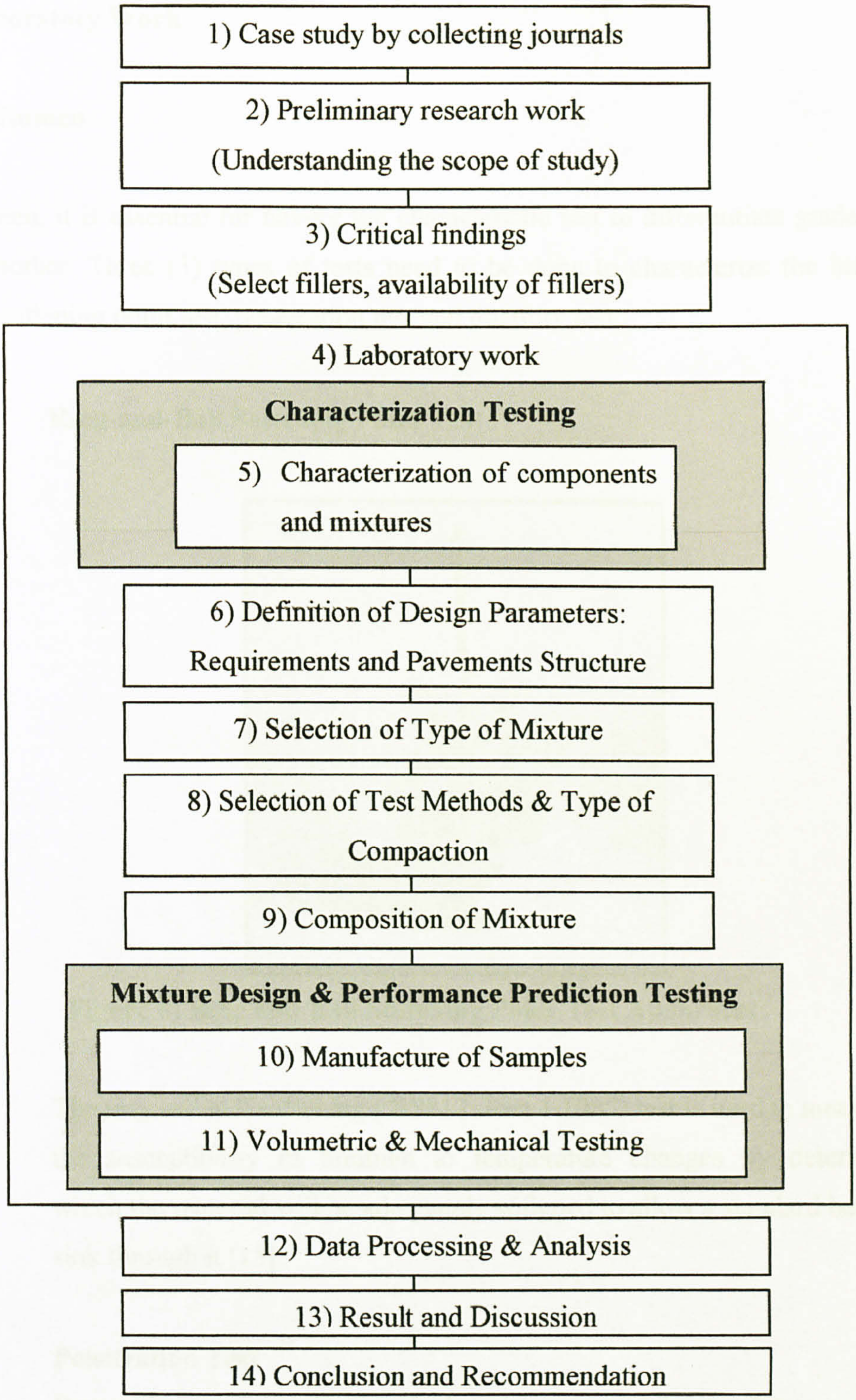


Figure 7. Elements of a methodology for bituminous mixtures with different fillers study (shaded areas are parts where testing has to be done)

3.1.1 Laboratory Work

3.1.1.1 Bitumen

For bitumen, it is essential for having the characteristic test to differentiate grade from one to another. Three (3) types of tests need to be done to characterize the bitumen which is softening point test, penetration test and ductility test.

- **Ring-and-Ball Softening Point Test**

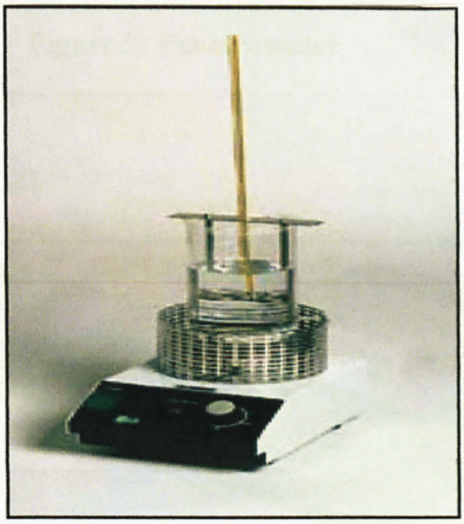


Figure 8: Ring and Ball Softening Point Test Apparatus

The ring and ball softening (BS812: Part 1:1985) test is used to measure the susceptibility of bitumen to temperature changes by determining which the material will be adequately softened to allow a standard ball to sink through it [13].

- **Penetration Test**

Penetration test gives an empirical measurement of the consistency of a material in terms of the distance a standard needle sinks into that material under a prescribed loading and time [13].

Figure 9: Penetrometer

- **Ductility Test**

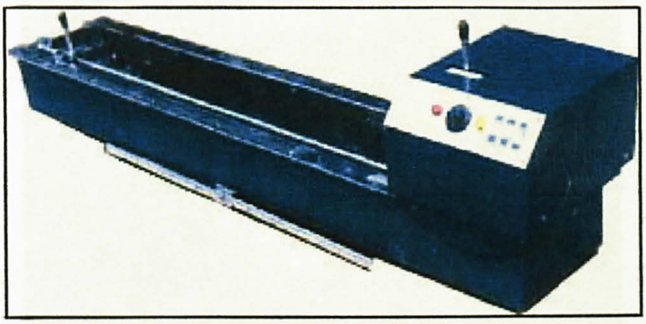


Figure 10: Ductilometer

Ductility is the distance in centimeters a standard sample of asphaltic material will stretch before breaking when tested on standard ductility test equipment at 25°C. The result if this test indicates the extent to which the material can be deformed without breaking [13].

- **Specific Gravity Test**

  The SG gravity for bitumen and filler was determined using the pycnometer. The SG of the coarse aggregate and fine aggregate were determined using the relevant BS standard.

3.1.1.2 Aggregate

In Malaysia, the aggregates used in the bituminous mixture must followed particular requirements provided by Jabatan Kerja Raya (JKR). There are six (6) tests usually used for determination of the physical properties of aggregate.

- **Sieve Analysis Test**

Figure 11: Sieve Shaker

Sieve Analysis of aggregate is a test where to determine the particle size distribution or gradation of fine and coarse aggregate. The aggregate's particle size distribution, or gradation is very important in which it can helps in determining the important properties of bituminous mixture such as permeability, stability, durability, stiffness, fatigue resistance, and workability.

- **Aggregate Abrasion Test/ Los Angeles (LA) Test**

Aggregates used in pavement should durable so that they can resist crushing under the roller. Many abrasion tests have been developed in order to evaluate the difficulty with which aggregate particles are likely to wear under attrition from traffic. The result of this test is called Aggregate Abrasion Value (AAV) and represent in percentage (%) form.

Figure 12: Los Angeles Abrasion Machine

- **Particle Density (Specific Gravity) & Water Absorption Test**

Figure 13: Weighing the aggregate during the specific gravity test

Specific gravity test is a measurement that determines the density of minerals. The specific gravity of a mineral determines how heavy it is by its relative weight to water. Water has a specific gravity of 1. If a sample tested and having a specific gravity of 2.5, it is 2.5 times heavier than water. Minerals with a specific gravity under 2 are considered light, between 2 and 4.5 averages, and greater than 4.5 heavy.

- **Flakiness Index and Elongation Index**

Figure 14: During Flakiness and Elongation Index Test

Flakiness and elongation indexes are the measures of particle shape. Flakiness index is defined as the percentage by mass of the particle in a sample of single-sized aggregate whose least dimension (thickness) is less than 0.6 times the mean dimension of the two sieves while the elongated index is defined as the percentage by mass of the particles in a sample of single-sized aggregate whose greatest dimension (length) is more than 1.8 times the mean dimension of the two sieves. Particle shape is important in that excessive amount of flaky or elongated material in aggregates can affect the workability of concrete. In bituminous mixtures flaky aggregate makes for a harsh mix and may also crack and break up during compaction by rolling.

3.1.1.3 Filler

Filler also have their own specific requirement which passes a 0.060 mm (No. 30) sieve, with at least 65 percent of the particles passing the 0.075 mm (No. 200) sieve. There are two (2) tests used to determine the physical properties for filler.

- **Specific Gravity Test**

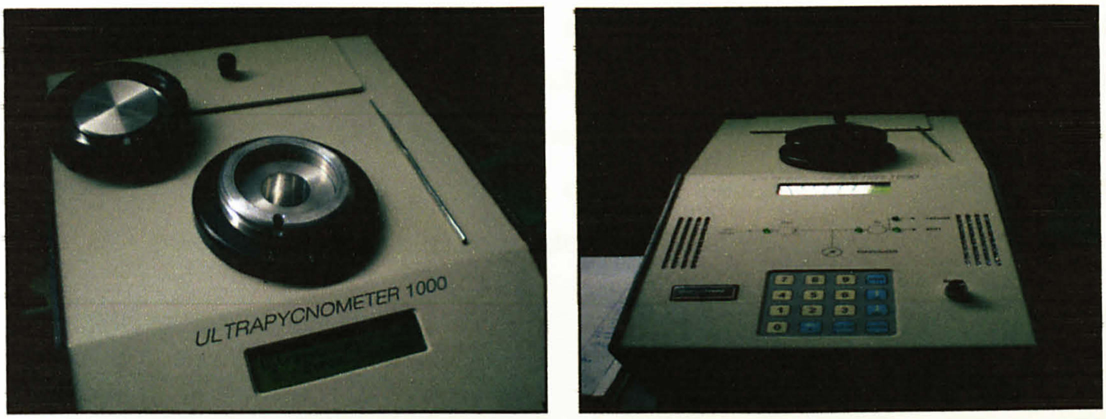


Figure 15: Ultrapycnometer

Specific gravity test is a measurement that determines the density of minerals to the density of water. In this context, the specific gravity of the fillers will be determined by using Ultrapycnometer 1000.

- **Scanning Electron Microscopy (SEM)**

Figure 16: Scanning Electron Microscope (SEM)

Scanning Electron Microscopy (SEM) is done by using a powerful microscope and use electrons instead of light and can produce a magnified image of the filler composition up until 100, 000X. The significant of this test is it will allow a particular mineral shape to be identified.

- **X-Ray Diffraction (XRD)**

X-ray diffraction (XRD) is a technique for qualitative and quantitative analysis of crystalline compounds. From this technique, the filler types and nature of crystalline phases present, amount if unstructured content, size and the orientation of crystallites could be obtained. From this technique, particular mineral (filler) characteristics could be identified.

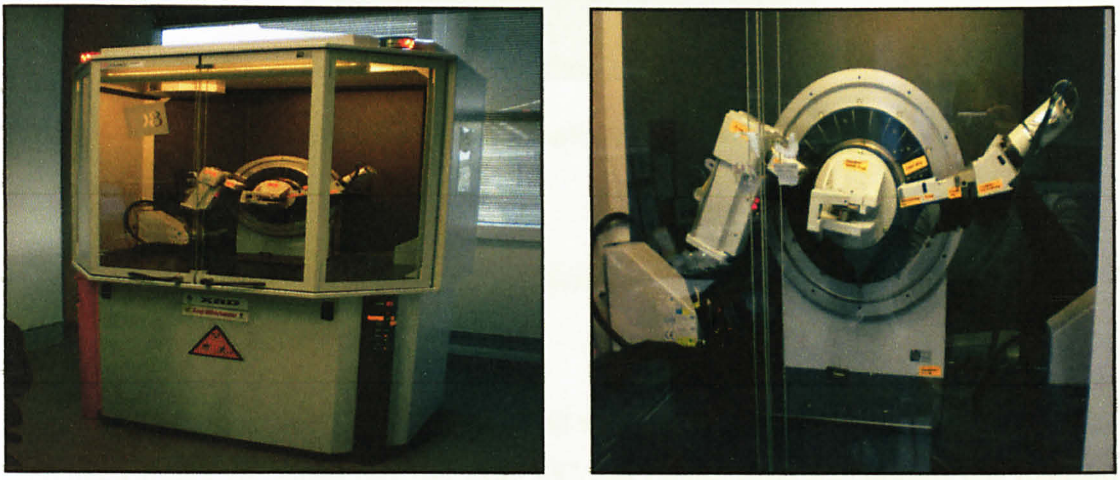


Figure 17: X-Ray Diffractometer

3.1.1.4 Marshall Mix Design

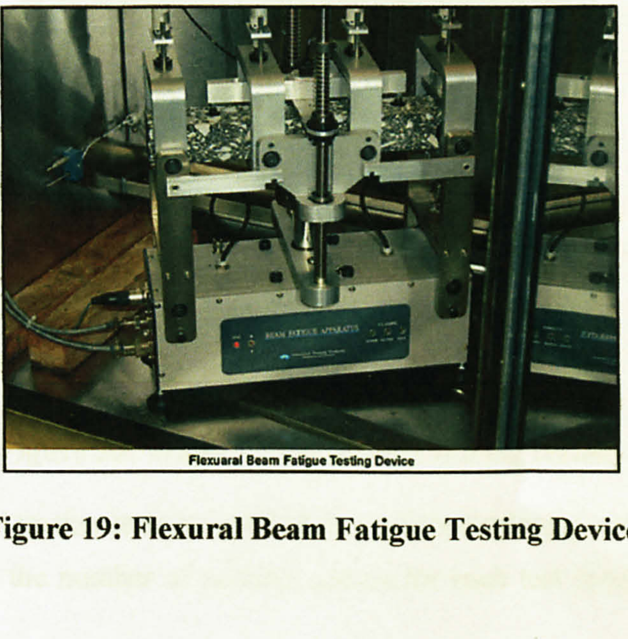
Marshall Mix Design is the most important test in this study. To design a bituminous mix, we have to choose the aggregate types, aggregate grading, bitumen grade and to determine the bitumen content which will optimize the engineering properties in relation to the desired behavior in service and Marshall mix design is one way to achieve it. From this test also, the optimum binder content for the bituminous mixture could be obtained and altogether with stability and flow value. Nonetheless, graph of voids in mineral aggregate and voids in total mix also could be obtained from this test.

Figure 18: Marshall Test Apparatus

3.1.2 Performance Test for Bituminous Mixture

3.1.2.1 Beam Fatigue Test

In this study, beam fatigue test was designed to provide data regarding the effects of the combined fillers i.e. lime-OPC, fly ash-OPC and crumb tire-OPC against the standard which contained just ordinary Portland cement on mixture fatigue performance and flexural stiffness including the variance in test measurements.



Flexuaral Beam Fatigue Testing Device

Figure 19: Flexural Beam Fatigue Testing Device

As for this test, four-point flexural beam fatigue was conducted on asphalt mixture beam specimens (2" x 2.5" x 15") at a temperature of 20°C and a range of strain levels by repetitively loading the samples in the center of the beam. As the specimen fatigues, microcracks are formed and the stiffness of the asphalt mix specimen decreases. As the microcracks increase, the specimen stiffness decreases rapidly, demonstrating failure. The number of cycles to failure, Nf, is defined as the loading cycle when the mixture stiffness drops to 50 percent of the original stiffness. Research has indicated that the cycles to failure (Nf) in the flexural beam fatigue test could be linked to the actual number of loading cycles essential to cause fatigue cracking of asphalt pavements. In the laboratory, the fatigue test is often used to compare the expected fatigue performance of different asphalt mixtures.

3.1.2.2 Wheel Tracking Test

The second performance test that will be done is wheel tracking test. This test is designed for testing the wearability and moisture damage potential of bituminous mixture by simulating roadway conditions. This test will provides information about the rate of permanent deformation from a moving, concentrated load.

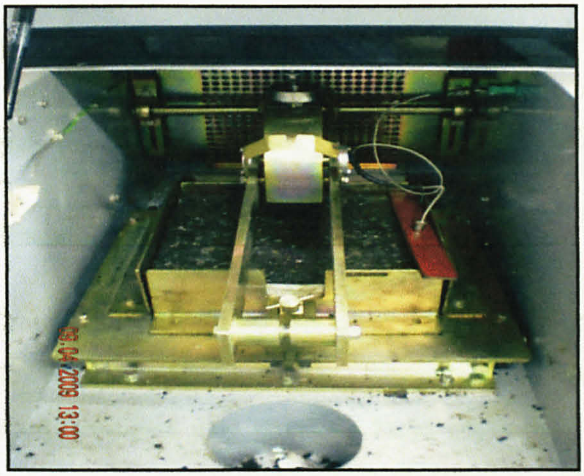


Figure 20: Wheel Track Sample during testing

Results of the wheel tracker tests are plotted on a graph displaying rut depth (typically in millimeters) versus the number of minutes passes for each test (normally 46 minutes).

Usually, the graph can reveal the number of passes to failure, the maximum rut depth occurring, and a stripping inflection point.

3.1.3 Hazard Analysis

For the hazard identification, several locations and sources at laboratory have been identified at which could potentially harm users such as oven, chemical substances, and etc. The objectives of this hazard study are:

- Prevent the accident from happening
- Increase productivity
- Prevent of properties damage

In highway laboratory, there are few potential sources on which the physical and chemical hazard could come in place such as:

- Eye

  There are many sources of laboratory materials which can potentially harm a person during laboratory works. It includes exposure to chemical splashes, vapor contact such as detergents, and solvents. To prevent this from happening, when working with these chemical substances, it is necessary to wear a safety goggle provided in the laboratory.

- Unsafe acts

  Unsafe acts are defined as acts done in the laboratory without following the labs rules and regulations. These acts could rule out to cause unwanted accidents and possibly harm one's life such as operating or working devices not according to instruction i.e. at unsafe speeds, using unsafe equipments or procedures, and etc…Hence, the rules and regulations must be followed in order to make sure unwanted things to happen.

- Unsafe conditions

Under this hazard, several sources can cause unsafe conditions to happen such as improperly guarded equipments, usage of defective equipments, running a hazardous procedure, unsafe storage, improper illumination and ventilation and poor housekeeping. From this, students must have good responsibilities in order to prevent this from happening.

- Dust

Dust originally comes from small particle of a solid substance and usually came with powdery characteristics such as very fine particle and moves freely in the air. From these characteristics, dust can give hazard to eye and breathing system. As for the solution, the dust mask and goggle is required to protect nose and eye from dust.

- Noise

Noise is defined as unwanted sound which having high intensity on which human can sustain. In highway laboratory, noise can come from the automatic compactor machine, Gyratory testing machine and many more. So, ear plugs and ear muffs are necessary to protect our ear having these hazards.

- Heat

In highway laboratory, the major source of heat comes from the oven. Heat can bring major hazard to human such as burn and scalded. To overcome this, one should wear gloves when dealing with oven and other hot equipment.

CHAPTER 4
RESULT AND DISCUSSION

4.1 Bitumen Characteristic Testing

4.1.1 Standard Penetration Test

The standard penetration test was conducted to determine the penetration value of the bitumen used.

Table 4.1: Result of Standard Penetration Test

Standard Penetration Test				
Temperature : 25°C		Load : 100 g	Time : 5 seconds	
Trial No.	Determination 1	Determination 2	Determination 3	Mean
A	88	88	85	87.00
B	86	86	84	85.33

Table 4.1 showing the result of the Standard Penetration Test done on the grade 80 bitumen. From the two (2) trials made, 3 points were selected on the samples located not less than 10mm from the side of the container and not less than 10mm apart. This to ensure there's no effect of the container or the tested points affecting other point's penetration value. From the results, it could be observed that the penetration value for sample A and B were showing values greater than 80 and lower than 100 and this confirmed that the bitumen used was similar to grade on which to be used throughout this study. The differences between the determinations also were within the range that is not exceeding four (4) and this result was satisfied [14].

4.1.2 Ring-and-Ball Softening Point Test

Table 4.2: Result of Softening Point Test

Softening Point Test			
Trial	Ball 1 (°C)	Ball 2 (°C)	Mean(°C)
A (Grade 80)	48	48.6	48.3
B (Grade 80)	47	47.8	47.4

Softening point value of trial 1: **48.3°C**

Softening point value of trial 2: **47.4°C**

The ring-and-ball softening point test is used to measure the susceptibility of the bitumen used to temperature changes by determining the temperature at which the material will be adequately softened to allow a standard ball to sink through it [13]. From Table 4.2, two trials of Grade 80 bitumen was made and tested. From the Manual on Pavement Design, the requirement for softening point test on bitumen cannot be less than 45°C and cannot exceed 52°C with the temperature differences between ball 1 and ball 2 not exceeding 1°C. The bitumen used in this study meet the requirement specified.

4.1.3 Ductility Test

Table 4.3: Result of Ductility Test

Ductility Test				
Sample	Mould No. 1	Mould No. 2	Mould No.3	Mean
A (Grade 80)	104.0cm	111.2cm	121.3 cm	112.17 cm

Ductility value of grade 80 bitumen = **112.17 cm**

Table 4.3 shows the experimental value from the ductility test of bitumen grade 80.The sample has been fabricated three (3) times into a dumb-bell shaped specimen and tested using the ductility test apparatus. From the three (3) samples, the mean of the data were taken and were evaluated as the ductility value of the bitumen. The results obtained have been accepted according to British Standard (BS) in which the elongation of the grade 80 bitumen must exceed 100cm.

4.2 Aggregate Characteristic Testing

4.2.1 Specific Gravity & Water Absorption Test

- **Fine Aggregate**

Table 4.4: Result of Specific Gravity for Fine Aggregate

			Test No.	
			1	2
Mass of saturated surface-dry sample in air	A	(g)	497	494
Mass of vessel containing sample and filled with water	B	(g)	1860	1856
Mass of vessel filled with water only	C	(g)	1557	1555
Mass of oven-dry sample in air	D	(g)	495.0	491.1

		Test No.		
		1	2	Average
Particle density on an oven-dried basis	$\frac{D}{A-(B-C)}$	2.55	2.54	2.545
Particle density on a saturated and surface-dried basis	$\frac{A}{A-(B-C)}$	2.56	2.56	2.560
Apparent particle density	$\frac{D}{D-(B-C)}$	2.58	2.58	2.580
Water Absorption (% of dry mass)	$\frac{100(A-D)}{D}$	0.40%	0.59%	0.495%

- **Coarse Aggregate**

Table 4.5: Result of Specific Gravity for Coarse Aggregate

			Test No.	
			1	2
Mass of saturated surface-dry sample in air	A	(g)	991	1075
Mass of vessel containing sample and filled with water	B	(g)	2170	2212
Mass of vessel filled with water only	C	(g)	1556	1562
Mass of oven-dry sample in air	D	(g)	984	1065

		Test No.		
		1	2	Average
Specific gravity on an oven-dried basis	$\frac{D}{A-(B-C)}$	2.61	2.51	2.56
Specific gravity on a saturated and surface-dried basis	$\frac{A}{A-(B-C)}$	2.63	2.53	2.58
Apparent specific gravity	$\frac{D}{D-(B-C)}$	2.66	2.57	2.62
Water Absorption (% of dry mass)	$\frac{100(A-D)}{D}$	0.71%	0.94%	0.83%

The JKR Manual on Pavement Design specified that the requirement for water absorption for coarse aggregate cannot exceed more than 2%. This is because the more absorptive the aggregate, the lower the durability of the resulting bituminous mixture. Water absorption is an indication of the bitumen absorption in the mix. The results of the tests show that the water absorption of the course aggregate used was lower than 1% which satisfy the requirement of JKR in the use of coarse aggregate.

4.2.2 Flakiness Index

Table 4.6: Result of Flakiness Index of Coarse Aggregate

Flakiness Index					
Size Fraction	**Square Mesh Grading**		**Mass of fraction to be tested, M_2 (g)**	**Flakiness Gauge**	
	Mass Retained (g)	**Percent Passing (%)**		**Mass retained by gauge (g)**	**Mass passing gauge (g)**
28.0 – 20.0	96	4.84	- (discarded)	- (discarded)	- (discarded)
20.0 – 14.0	1102	55.63	1102	1013	89
14.0 – 10.0	607	30.64	607	564	43
10.0 – 6.30	176	8.88	176	160	16
Total Masses, M_1 (g)	1981	100	$\Sigma M_2 = 1885$	1737	$\Sigma M_3 = 148$

$$FlakinessIndex = \frac{\Sigma M_3}{\Sigma M_2} x100\%$$

$$= \frac{148}{1885} x100\%$$
$$= 7.85\%$$

The Flakiness Index value of 7.85% obtained met the material specification requirement for coarse aggregates as specified by JKR Manual on Pavement Design that should not exceed 30%.

4.2.3 Elongation Index

Table 4.7: Result of Elongation Index of Coarse Aggregate

Elongation Index					
Size Fraction	**Square Mesh Grading**		**Mass of fraction to be tested, M_2 (g)**	**Elongation Gauge**	
	Mass Retained (g)	**Percent Passing (%)**		**Mass retained by gauge (g)**	**Mass passing gauge (g)**
28.0 – 20.0	96	4.84	- (discarded)	- (discarded)	- (discarded)
20.0 – 14.0	1102	55.63	1102	276 (203)	826 (899)
14.0 – 10.0	607	30.64	607	312 (156)	295 (451)
10.0 – 6.30	176	8.88	176	102 (77)	74 (99)
Total Masses, M_1 (g)	1981	100	$\Sigma M_2 = 1885$	$\Sigma M_3 = 690$ (436)	1195 (1449)

$$Elongation Index = \frac{\Sigma M_3}{\Sigma M_2} x100\%$$

$$= \frac{436}{1885} x100\%$$
$$= 23.1\%$$

As the JKR requirement for Elongation Index for coarse aggregate should not exceed 30% the coarse aggregate used in this study fulfill this requirement from that results obtained.

4.2.4 Los Angeles Abrasion Test

Table 4.8: Result of Los Abrasion Test of Coarse Aggregate

Los Angeles Abrasion Test						
				Test No.		
				1	2	Mean
Mass of aggregate retained on No.4 ASTM sieve		M_1	(kg)	5	5	
Mass of material passing No.12 ASTM sieve		M_2	(kg)	1.261	1.252	
Los Angeles abrasion value	$\frac{M_2}{M_1} \times 100\%$			25.2%	25.0%	25.1%

From the JKR Manual, the value of the Los Angeles Abrasion loss (%) must not exceed 50. Hence, the coarse aggregate tested satisfy this requirement as the abrasion value was 25.1%.

4.3 Filler Characteristic Testing

4.3.1 Specific Gravity

Table 4.9: Result of Specific Gravity of Crumb Tire

Run	**Volume (cm^3)**	**Density (g/ cm^3)**
1	1.3203	1.2663
2	1.3441	1.2440
3	1.3327	1.2546
4	1.3385	1.2492
5	1.3338	1.2536
6	1.3405	1.2473
Average	1.3350	**1.247**

Table 4.10: Result of Specific Gravity of Fly Ash

Run	Volume (cm^3)	Density (g/cm^3)
1	1.8057	2.8123
2	1.7943	2.8301
3	1.8017	2.8184
4	1.8051	2.8133
5	1.8091	2.8070
6	1.8201	2.7900
Average	1.806	**2.812**

Table 4.11: Result of Specific Gravity of Hydrated Lime

Run	Volume (cm^3)	Density (g/cm^3)
1	0.6596	2.8075
2	0.6405	2.8909
3	0.6474	2.8602
4	0.6337	2.9219
5	0.6422	2.8835
6	0.6490	2.8529
Average	0.6454	**2.870**

The specific gravity test for filler was obtained using the Ultrapycnometer 1000. This equipment is normally used for measuring the true density and volume of powders, granules, tablets, actives, and blends. Table 4.9 to 4.11 shows the results of the specific gravity test conducted for the all fillers used in this study. These values will later be used to determine the specific gravity of the aggregate and bituminous mixtures.

4.3.2 Scanning Electron Microscope (SEM)

Below are the results of the particles shaped of the three types of fillers that will be used in this study. These pictures were obtained from the Scanning Electron Microscope (SEM).

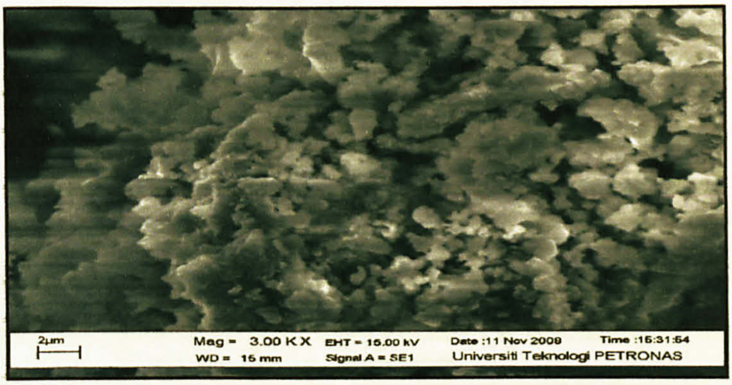


Figure 21: Hydrated Lime Particle

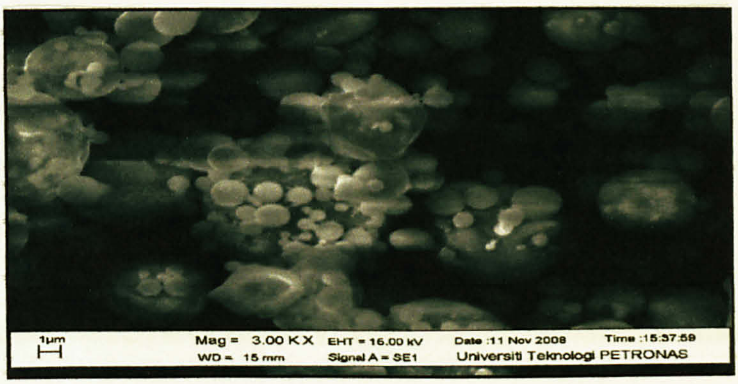


Figure 22: Fly Ash Particle

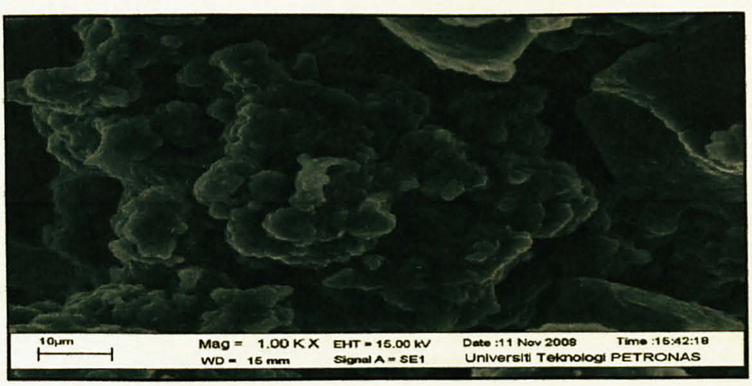


Figure 23: Crumb Tire Particle

4.3.3 X-Ray Diffraction (XRD)

Below are the results of X-Ray Diffraction (XRD) done on the three types of fillers that were used. As mention in the methodology part, XRD is a technique for qualitative and quantitative analysis of crystalline compounds and below are the results:

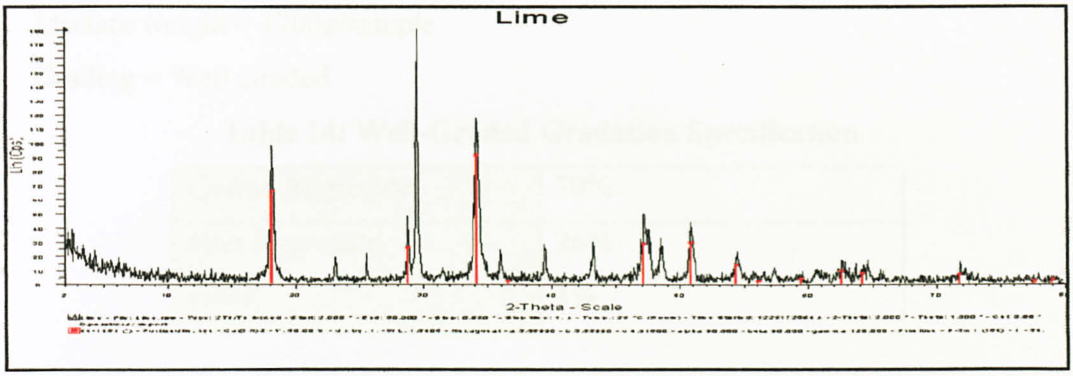


Figure 24: Hydrated Lime XRD

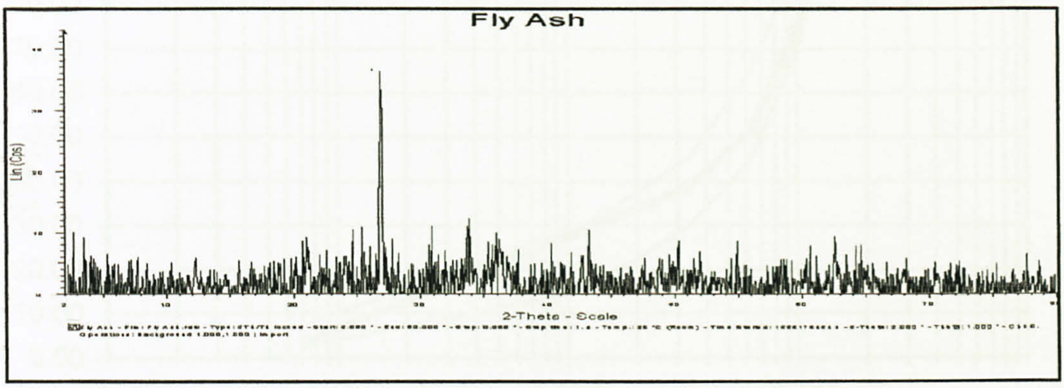


Figure 25: Fly Ash XRD

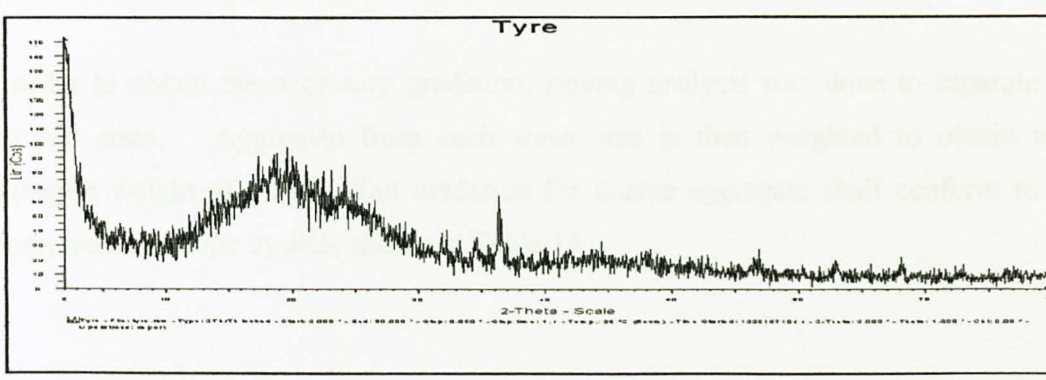


Figure 26: Crumb Tire XRD

4.4 Marshall Mix Design

4.4.1 Marshall Methodology

The Marshall samples were done according to Highway Lab Manuals. All samples have been done according to the descriptions below:

1. Mixture weight = 1200g/sample
2. Grading = Well Graded

Table 14: Well-Graded Gradation Specification

Coarse Aggregate	70%
Fine Aggregate	26%
Filler	4%

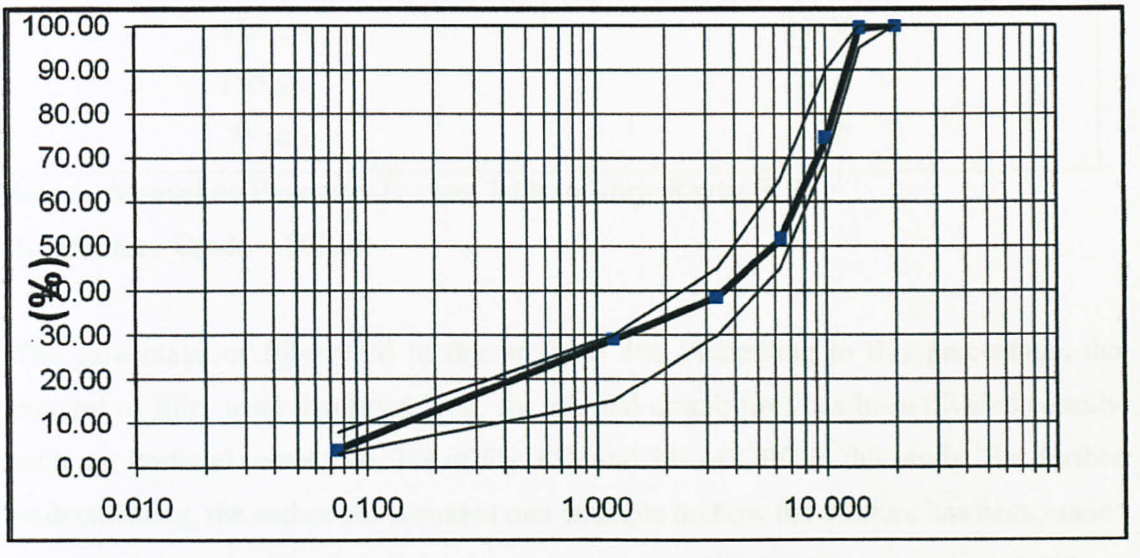


Figure 27 : Well-Graded Granite Profile

In order to obtain the necessary gradation, sieving analysis was done to separate the required sizes. Aggregate from each sieve size is then weighted to obtain total aggregate weight of 1.2kg. Well gradation for coarse aggregate shall conform to the appropriate envelope by JKR shown in Table 15.

Table 15: Well Gradation Limits for Asphaltic Concrete

Mix Type	Wearing Course
Mix Designation	ACW14
B.S Sieve Size	% Passing by Weight
37.5 mm	-
28.0 mm	-
20.0 mm	100
14.0 mm	80-95
10.0 mm	68-90
5.0 mm	52-72
3.35 mm	45-62
1.18 mm	30-45
425 μm	17-30
150 μm	7-16
75 μm	4-10

Source: Manual on Pavement Design, Jabatan Kerja Raya (JKR)

3. Bitumen Grade = 80/100

The percentage of filler used in this study is 4%. According to this percentage, the amount of filler used (hydrated lime, fly ash and crumb tire) has been divided equally with the Portland cement i.e. 2% of Fly Ash and 2% of OPC in this study. For further understanding, the author has included one example on how the mixture has been made:

Bituminous Mixture Calculation example for one Marshall sample:

Mixture weight = 1200g

Coarse aggregate weight = (70/100) x 1200 = 840g

Fine aggregate weight = (26/100) x 1200 = 312g

Filler weight = (4/100) x 1200 = 48g (24g for OPC and 24g for Fly Ash)

Bitumen content = 4.5%   %bit=x/(x+1200)

Hence, x = 57g

The total mix weight = 1200 + x = 1200 + 57 = 1257 g

In the analysis of the results several graphs were plotted in order to find the Optimum Binder Content (OBC). The graphs are:

- Density
- Porosity
- VMA
- Stability
- Marshall Quotient (stiffness)

The average bitumen content percentage from the stability, density, VMA and porosity are calculated in order to obtain the optimum bitumen content for each mixture. (Refer Appendix B)

4.4.2 Marshall Samples Data Analysis

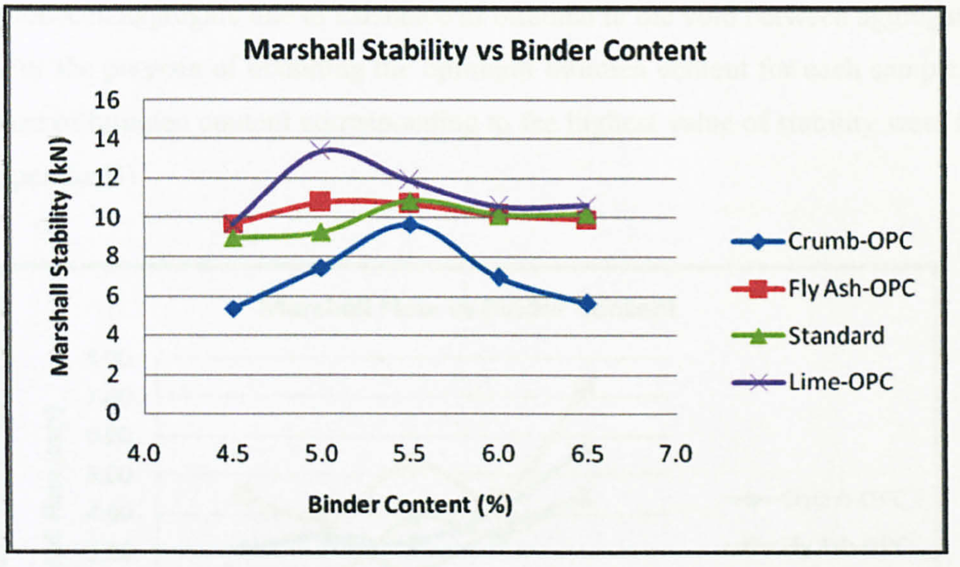


Figure 28: Marshall Stability vs. Binder Content

Figure 28 shows the Marshall stability curves for each combination of bituminous mixture. It also display the result of Marshall stability as a function of varying the bitumen content and the filler type.The values were obtained directly from the Marshall Testing Machine. However the value should be corrected by multiplying by a certain correction factor based on the height of the sample. Marshall stability show the maximum load the sample can sustained before it failed. Stability of combination 50% of hydrated lime incoorporated with 50% of opc shows highest value compared to standard sample which consists only OPC as a filler, fly ash-OPC and crumb-OPC combinations. By referring to the figure itself, we also could observed that crumb-OPC combination indicating lower stability than the standard samples. This indicates that this combination might not be suitable for commercial purposes since it tend to lower the stability and infact increase the cost because of the combination of the crumb with opc. From the figure itself, as from the Marshall stability point of view, hydrated lime helps give the highest stability among all other fillers selected. It was observed that the Marshall Stability increases as the bitumen content increases from 4.5% to 5% and then decreases as the bitumen content increases. The higher Marshall stability caused by increasing the bitumen content up to optimum value and which the bitumen tend to fill the voids between the aggregate grains. The mix will continue to gain strength from contact between aggregate due to existance of bitumen in the void between aggregate.

For the purpose of obtaining the optimum bitumen content for each sample, the percentage of bitumen content corresponding to the highest value of stability were taken (See Appendix B).

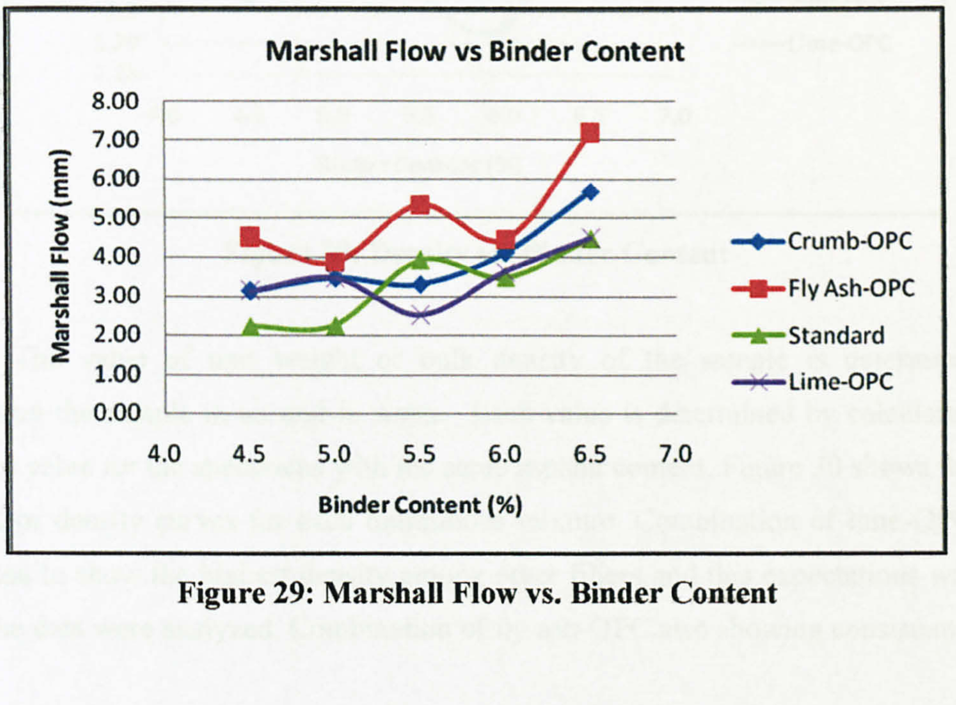


Figure 29: Marshall Flow vs. Binder Content

The flow value refers to the total amount of deformation that occurs up to the point where the load begins to decrease. The flow is measured at the same time as the Marshall stability and flow value has a significant correlation with the amount of bitumen used in the mixture. According to Figure 29, it is shown that as the bitumen content in the mixture increased, the value of flow increased. As we can see, the lowest flow generally produced by the combination of lime-OPC filler type. Meanwhile, fly ash-OPC combination gave us the highest flow of all even comparing it to the standards mixture. From here, hydrated lime once again provides lowest flow compared to other type of fillers study. The graph of flow does not considered in determining the optimum bitumen content(OBC) of the mixture but it is used in order to determine whether the OBC content obtained from the Density, Stability and VMA graphs meets the standards or not (See Appendix B).

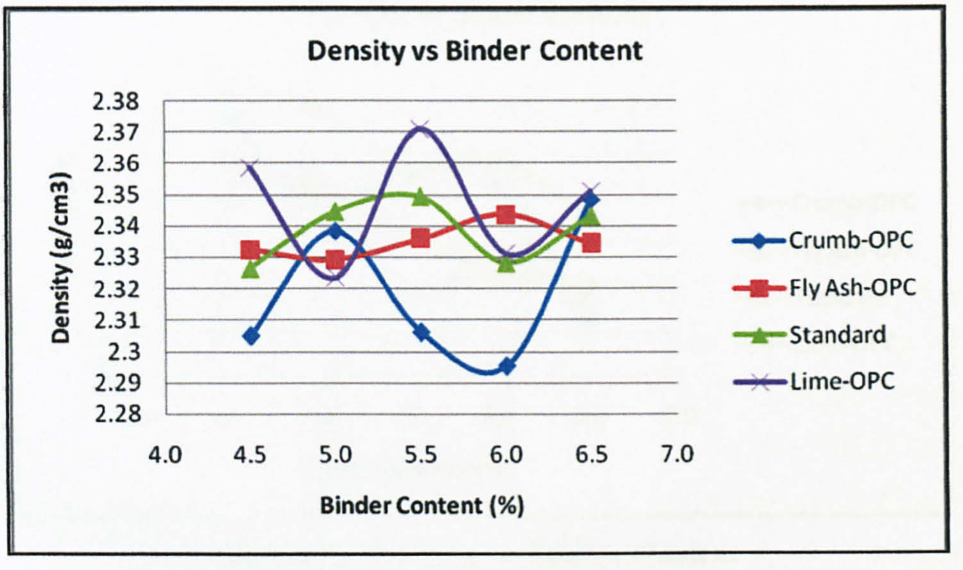


Figure 30: Density vs. Binder Content

The value of unit weight or bulk density of the sample is determined by weighting the sample in air and in water. Each value is determined by calculating the average value for the specimens with the same asphalt content. Figure 30 shows the unit weight or density curves for each bituminous mixture. Combination of lime-OPC was expected to show the highest density among other fillers and this expectations was met after the data were analyzed. Combination of fly ash-OPC also showing consistent result as the density differences is small as the bitumen content increase. But for the fly ash-OPC and crumb-OPC, the density are showing lower density value than the standard sample and this may not suitable for commercial purpose. But note that, 3 samples were made for each combination and this may needs more samples manufactured following by further studies and analysis before conclusion can be made about commercializing it. As for density, hydrated lime provides highest density as compared to the other fillers and standard studied.

The samples were compacted using Marshall compactor. In order to select the optimum percentage of binder content of each mixture, bitumen content corresponding the highest value of unit weight should be taken into consideration and will be calculated as the average with other variables (Refer Appendix B).

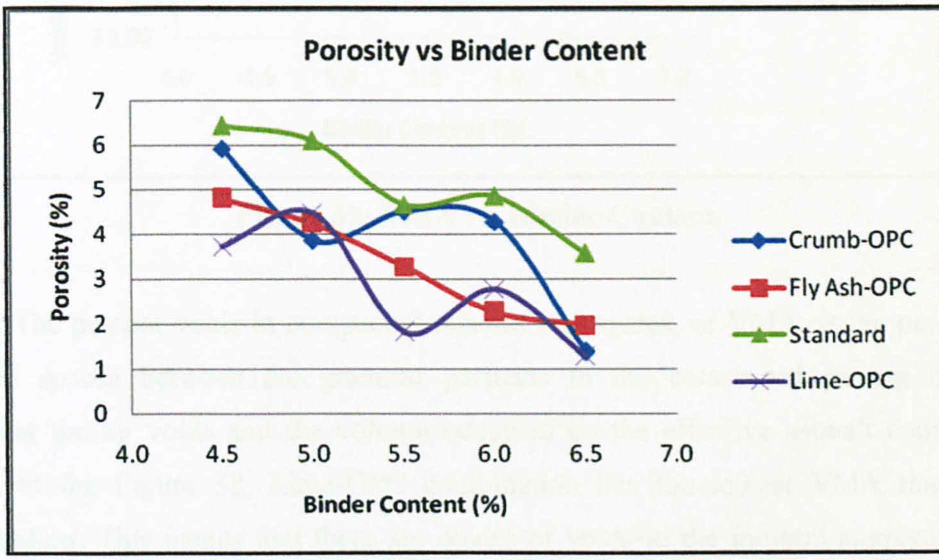


Figure 31: Porosity vs. Binder Content

Porosity relates to the amount of air voids in the mix. It does not however consider the inter-connectivity of these voids. It represents the volume in the mix that is not occupied by either aggregate or bitumen.

From Figure 31, the porosity of all combinations generally are decreasing as the bitumen content increasing and This kind of situation is happening because the bitumen itself is acting as a lubricant to the mix and this has resulting in decreasing the porosity value. From this figure, all fillers combination with OPC are showing lower porosity than the standards. This indicates that the hydrated lime, crumb tire and fly ash are helpful in lowering the porosity value in the bituminous mixture. But compared to all, hydrated lime provides the lowest porosity value and this mean if it were to select the best fillers for lowering the porosity value, hydrated lime will be selected.

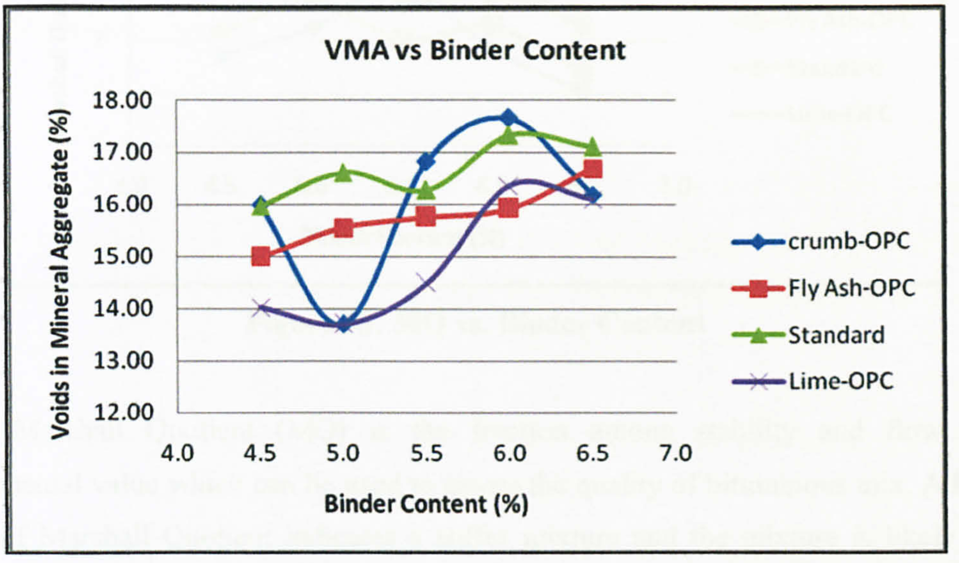


Figure 32: VMA vs. Binder Content

The percent voids in compacted mineral aggregates, or VMA, is the percentage of void spaces between the granular particles in the compacted paving mixture, including the air voids and the volume occupied by the effective asphalt content. As shown in the Figure 32, Lime-OPC combination has the lowest VMA than other combination. This means that there are plenty of voids in the mineral aggregate itself and the total void space between small particles is greater than that between large particles.

VMA must be sufficiently high to ensure that there is room for asphalt coating at adequate film thickness plus the required air voids remaining after compaction that is available for thermal expansion of asphalt during hot weather. If VMA is too small, the mix may suffer durability problem. On the other hand, if VMA is too large, the mix may show stability problem and may be uneconomical. In determining the optimum bitumen content, the minimum value of VMA of each mixture were considered. The reason is to minimize the voids in the mixture and in the aggregate itself.

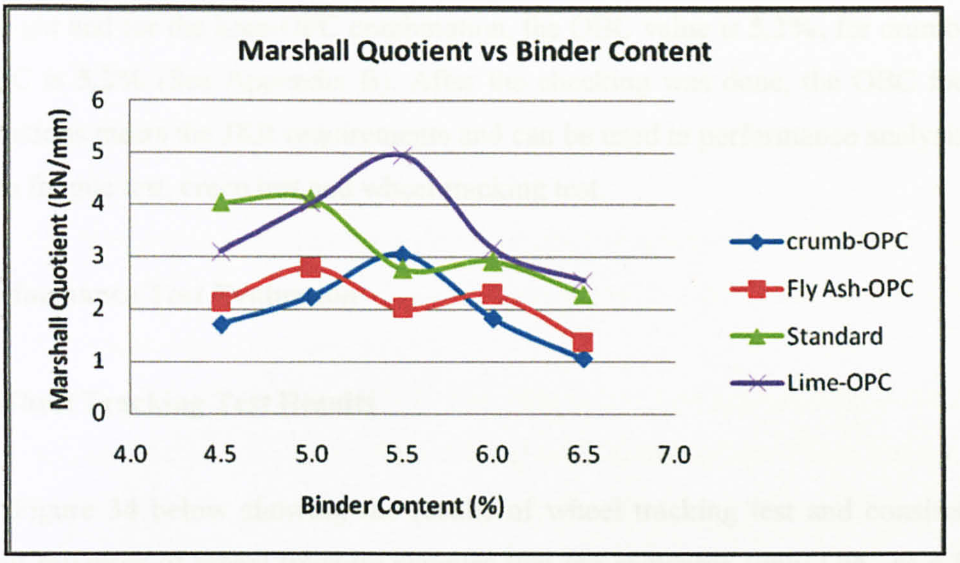


Figure 33: MQ vs. Binder Content

Marshall Quotient (MQ) is the fraction among stability and flow. It is experimental value which can be used to assess the quality of bituminous mix. A higher value of Marshall Quotient indicates a stiffer mixture and the mixture is likely more resistance to permanent deformation (Robert et al, 1996; Shell, 1990).

Figure 33 demonstrate that the result of Marshall quotient as a function of varying the bitumen content and filler type. It is observed that the Marshall quotient for lime-OPC and crumb-OPC combinations increases as the bitument content increases from 4.5% to 5.5% and then decreases as the binder content increases. For the fly ash-OPC combination and standard samples, the Marshall quotient has been unstabled since the value at 5.5% binder content is lower than 5.0%. This result maybe due to some error during the Marshall sample preparation. But overall, hydrated lime gained highest MQ compared to the rest and this proceed to conclusion that hydrated lime is the best fillers compared to fly ash and crumb tire from Marshall Mix Design point of view.

4.4.3 Optimum Binder Content (OBC)

From all the graphs plotted (Figure 28 – 33), the data was analyzed and the value of the optimum binder content (OBC) have been determined. For the standards mixture, the obtained OBC was **5.1%,** fly ash-OPC combination, the OBC value is **5.3%** of the total mix weight and for the lime-OPC combination, the OBC value is **5.2%,** for crumb-OPC the OBC is **5.2%** (See Appendix B). After the checking was done, the OBC for both combinations meets the JKR requirements and can be used in performance analysis such as beam fatigue test, creep test and wheel tracking test.

4.5 Performance Test Evaluation

4.5.1 Wheel Tracking Test Results

Figure 34 below showing the results of wheel tracking test and consists of 4 different mixtures of wheel tracking samples that are standards (only OPC as a filler), crumb-OPC, fly ash-OPC and lime-OPC filler combinations.

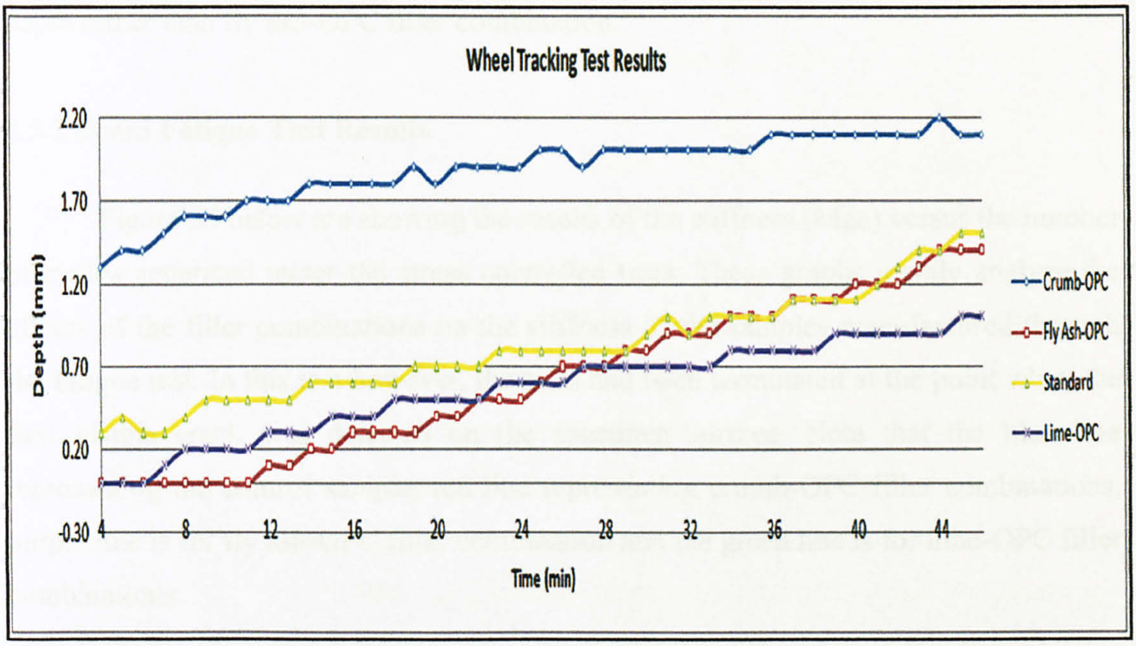


Figure 34: Wheel Tracking Test Results

As can be seen, the blue line represent crumb-OPC filler combination and the rutting depth was high even at the initial stage of the test and keep increasing until the end of the test. Note also, the rutting depths was higher than the standard sample prepared and this can be concluded that the combination done was not suitable for improving the pavement rutting resistance. This maybe happen due to insufficient compaction of bituminuous mixture layers during construction. In real application, if it is not compacted enough initially, the pavement may continue to densify under traffic loads.

This also occurs maybe because of improper mix design and as for example error caused by excessively high bitumen content, excessive mineral filler and insufficient amount of angular aggregate particles.

Moving on to the purple and red lines. The purple line represent lime-OPC filler combination and red line represent fly ash-OPC filler combination. These lines provide better resistance to rutting problems and improve the pavement resistance to rutting as we can see the lines were generally below the standard mixture rutting line results. But if there were to select the best additive to provide best resistance to rutting, it will be the combination of lime-OPC filler combination since the data shows consistent in rutting depth rather than fly ash-OPC filler combination.

4.5.2 Beam Fatigue Test Results

Figure 35 below are showing the results of the stiffness (Mpa) versus the number of cycles generated under the stress controlled tests. These graphs mainly analyze the effects of the filler combinations on the stiffness of the samples manufactured through the fatigue test. In this test however, the tests had been terminated at the point when the first visible crack was detected on the specimen surface. Note that the blue line representing the control sample, red line representing crumb-OPC filler combinations, purple line is for fly ash-OPC filler combination and the green line is for lime-OPC filler combinations.

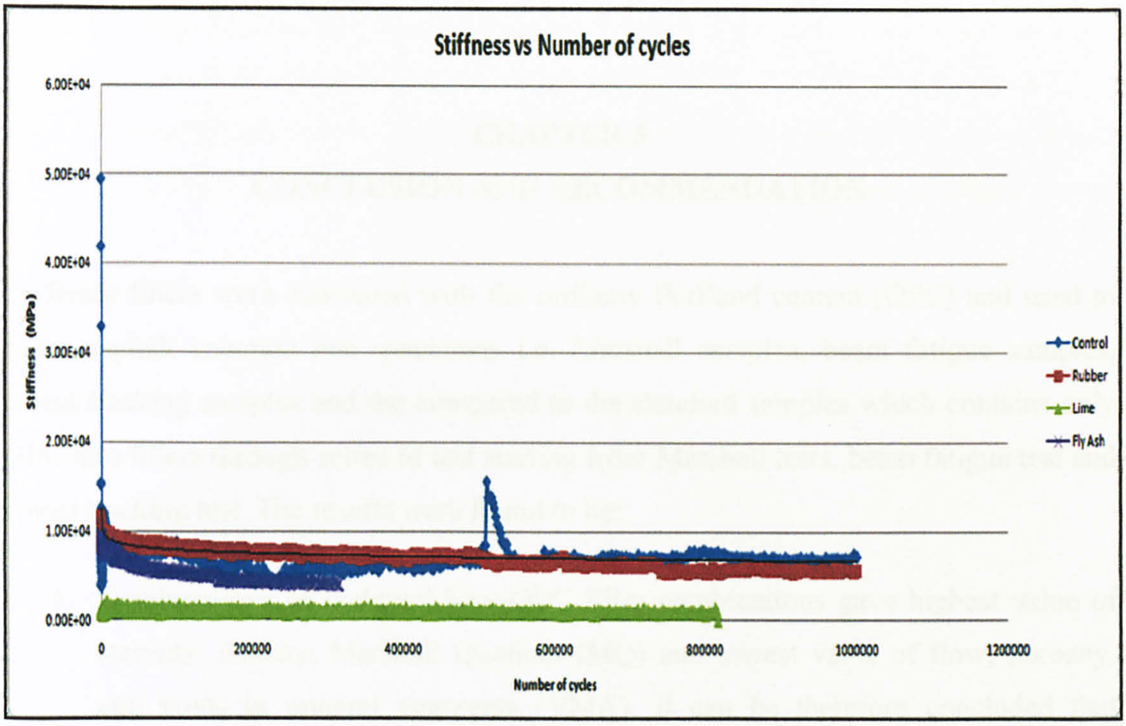


Figure 35: Stiffness vs. Number of cycles

The crumb-OPC filler combination indicates that they have the highest stiffness at the initial stage of the test and even exceed the stiffness of the standard sample and this projected until the end of the cycles. However, for the lime-OPC combination, the results showing they have the lowest stiffness and this was not as expected since hydrated lime so far provides the best solution to improve the physical and performance characteristics of the bituminous mixture. This maybe occurs due to some error in the sample preparation i.e. insufficient or excessive amount of aggregate, filler, and even bitumen. As for the fly ash-OPC combination, the beam has achieve its fatigue life at 320000 cycles and this indicate in the real-field applications, this combination are not suitable for long design life pavement since it simulate short fatigue life. But overall, each type of the combinations can be used depending on the requirements needed i.e. strength, cost optimization, availability and etc…

CHAPTER 5
CONCLUSION AND RECOMMENDATION

Different fillers were combined with the ordinary Portland cement (OPC) and used to make asphalt concrete test specimens i.e. Marshall samples, beam fatigue samples, wheel tracking samples and the compared to the standard samples which contains only OPC as a fillers through series of test starting from Marshall tests, beam fatigue test and wheel tracking test. The results were found to be:

1. Combinations of hydrated lime-OPC filler combinations gave highest value of stability, density, Marshall Quotient (MQ) and lowest value of flow, porosity, and voids in mineral aggregate (VMA). It can be therefore concluded that hydrated lime is the best selection of fillers that can be combined in the bituminous mixture rather than crumb tire and fly ash from Marshall testing point of view.
2. Hydrated Lime once again performed well in wheel tracking test as the combination results in the lowest rutting depth as time increase compared to other combinations and standard samples. But for crumb-OPC filler combinations, the wheel tracking results was not desirable since the rutting depth was higher than the standard sample result.
3. In beam fatigue test evaluation, the hydrated lime-OPC filler combination were not up to the result expected since the combination stiffness was the lowest among other combination and even the standard samples. This maybe occurs due to error during sample preparation or compaction stage.
4. All this conclusion were based on samples prepared and so far for each filler combinations, 3 samples were made at most and this could affect the accuracy of the result since the quantity of the samples made were small. This can be verifying by running the test repeatedly and by taking average of the stiffness

reading. But due to time constraint, only two samples were made and this might still too early to say that all the results and conclusions made were accurate.

5. Generally, the performance of asphalt concrete mixes prepared using crumb tire, fly ash and hydrated lime as fillers were better than origin bitumen mixes.

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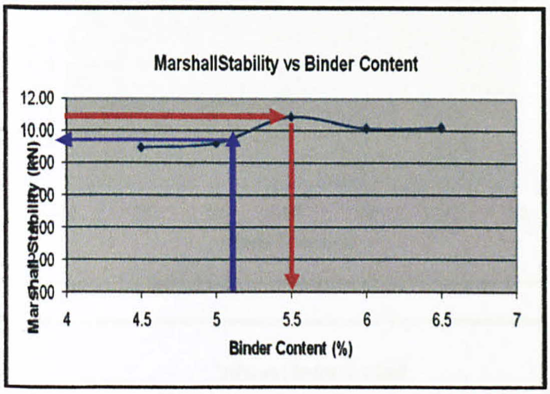
APPENDICES

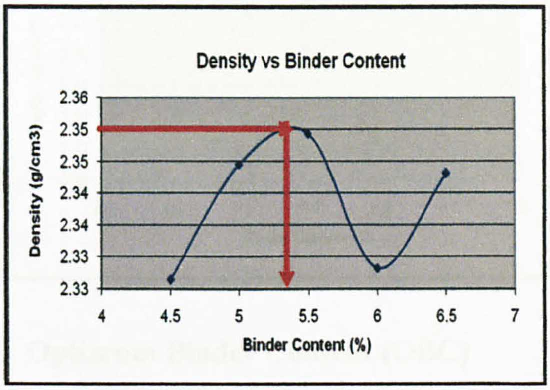
1) Appendix A : Marshall Test Property Curves
2) Appendix B: Standard Procedure of Characteristics and Performance Testing

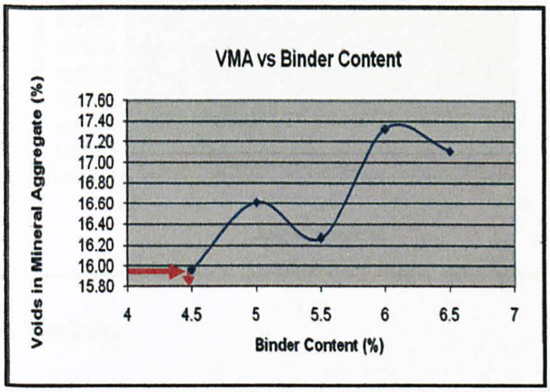
Appendix A

Marshall Test Property Curves

Standard graphs analysis





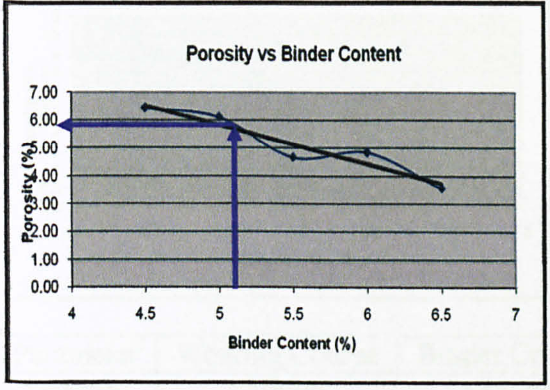


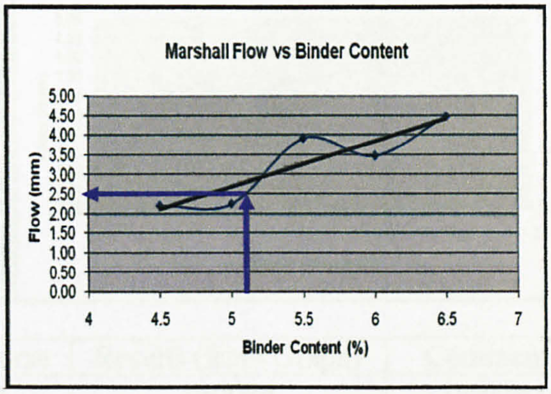
Optimum Binder Content (OBC)

Parameter	OBC (% by weight)
Density	5.3
Stability	5.5
VMA	4.5

- **OBC** = (5.3 + 5.5 + 4.5)/3
  = 5.1%

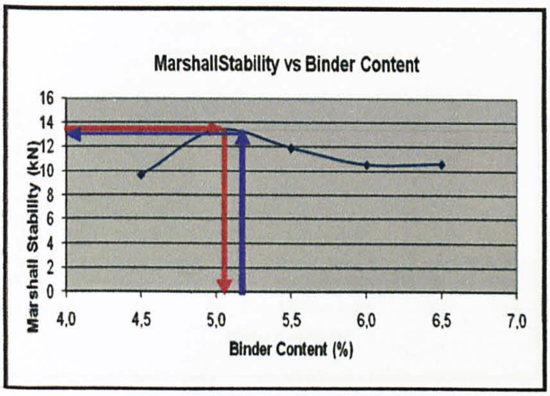
Checking..

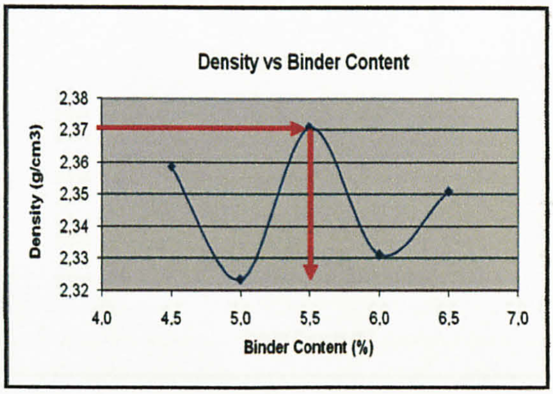


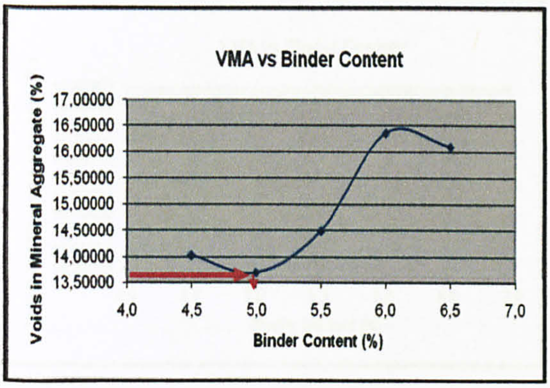


Parameter	Wearing Course	Binder Course	Results (from Graph)	Comment
Stability	>500kg	>450kg	950kg	**Passed**
Flow	>2.0 mm	>2.0 mm	2.50mm	**Passed**
Porosity	3%-5%	3%-5%	5%	**Passed**

Lime-OPC combination graphs analysis





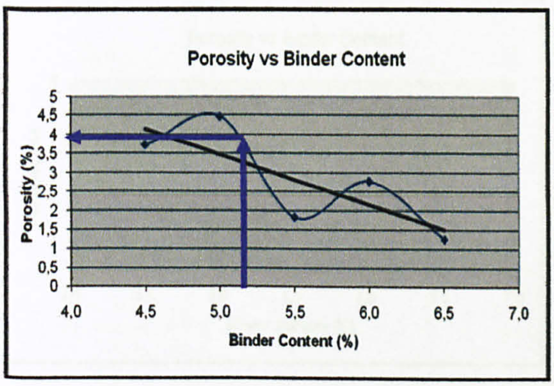


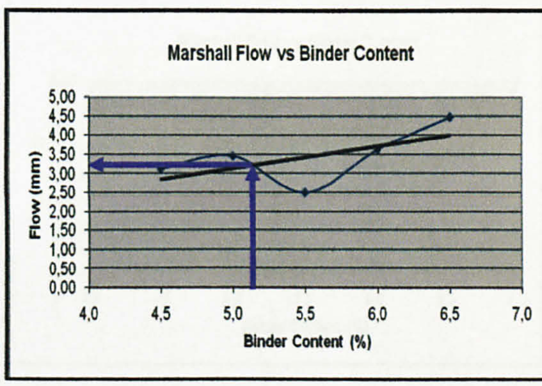
Optimum Binder Content (OBC)

Parameter	OBC (% by weight)
Density	5.5
Stability	5.1
VMA	4.9

- **OBC** = (5.5 + 5.1 + 4.9)/3
  = 5.2%

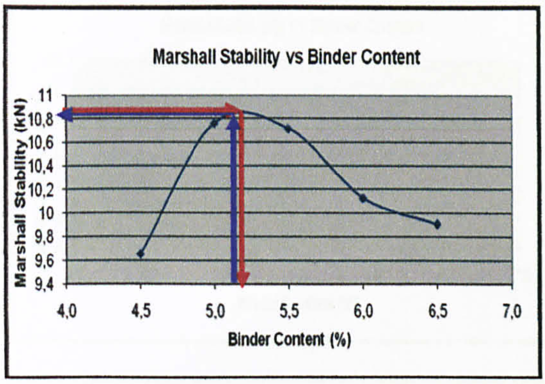
Checking..

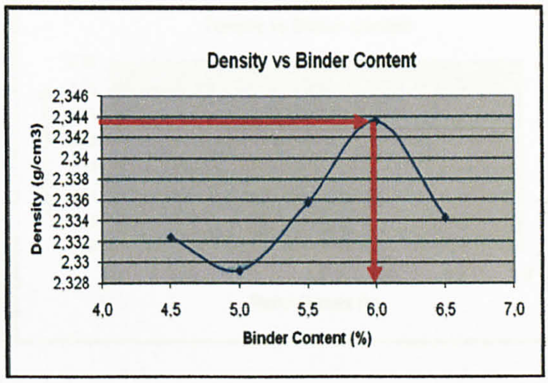


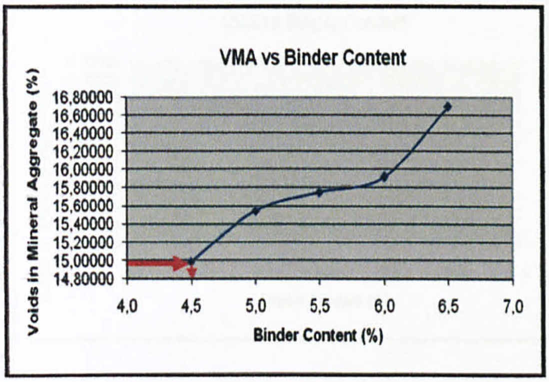


Parameter	Wearing Course	Binder Course	Results (from Graph)	Comment
Stability	>500kg	>450kg	1300kg	**Passed**
Flow	>2.0 mm	>2.0 mm	3.25mm	**Passed**
Porosity	3%-5%	3%-5%	4%	**Passed**

Fly Ash-OPC combination graphs analysis





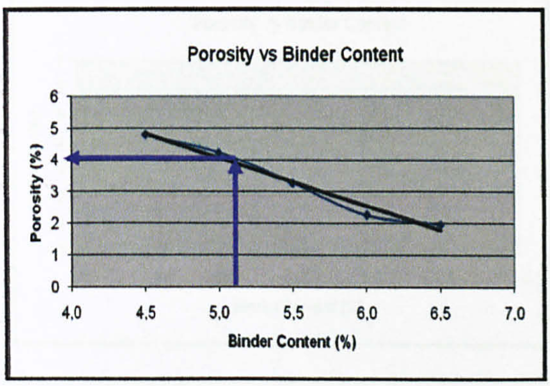


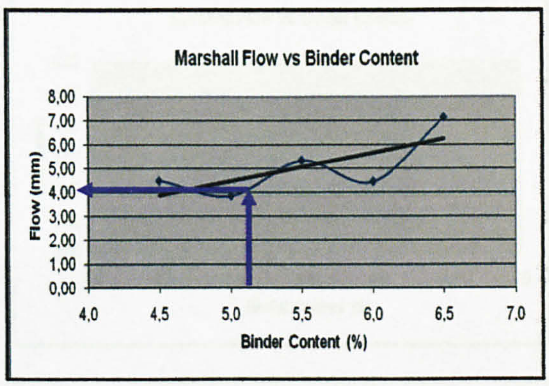
Optimum Binder Content (OBC)

Parameter	OBC (% by weight)
Density	6.0
Stability	5.3
VMA	4.5

- **OBC** = (6.0 + 5.3 + 4.5)/3
  = 5.3%

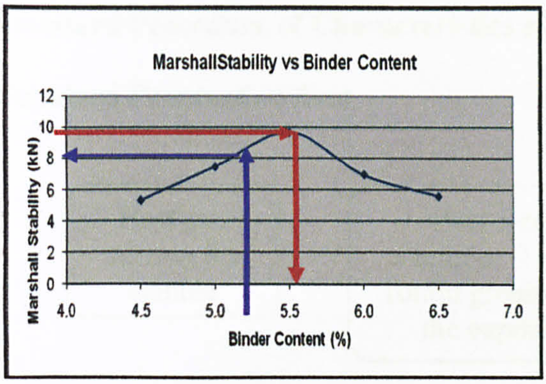
Checking..

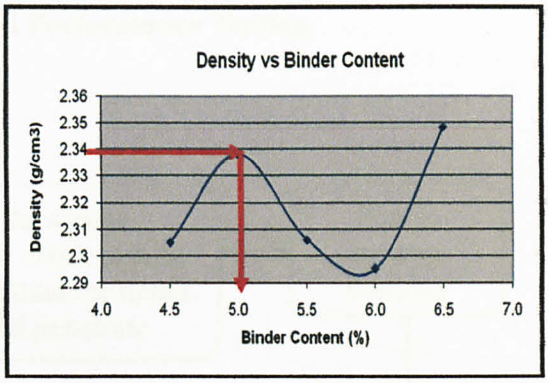


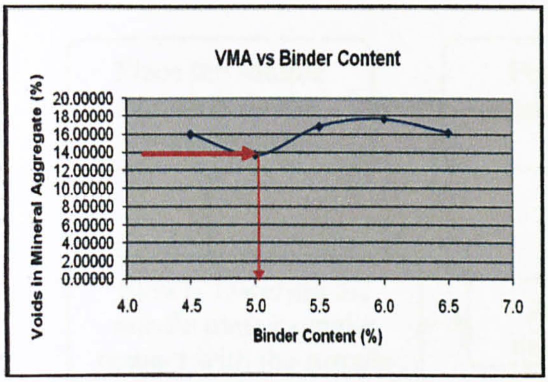


Parameter	Wearing Course	Binder Course	Results (from Graph)	Comment
Stability	>500kg	>450kg	1080kg	**Passed**
Flow	>2.0 mm	>2.0 mm	4.00mm	**Passed**
Porosity	3%-5%	3%-5%	4%	**Passed**

Crumb Tire-OPC combination graphs analysis





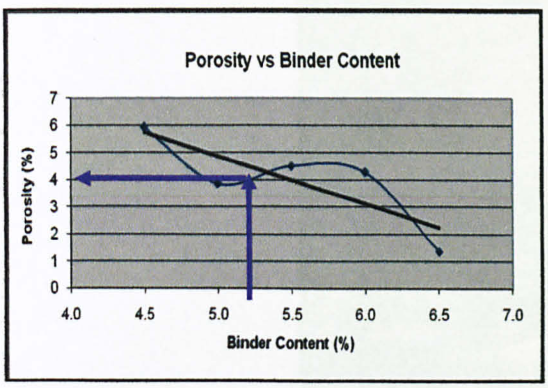


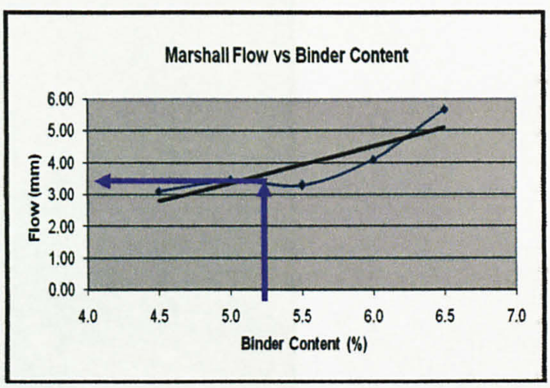
Optimum Binder Content (OBC)

Parameter	OBC (% by weight)
Density	5.0
Stability	5.5
VMA	5.0

- **OBC** = (5.0 + 5.5 + 5.0)/3
  = 5.2%

Checking..



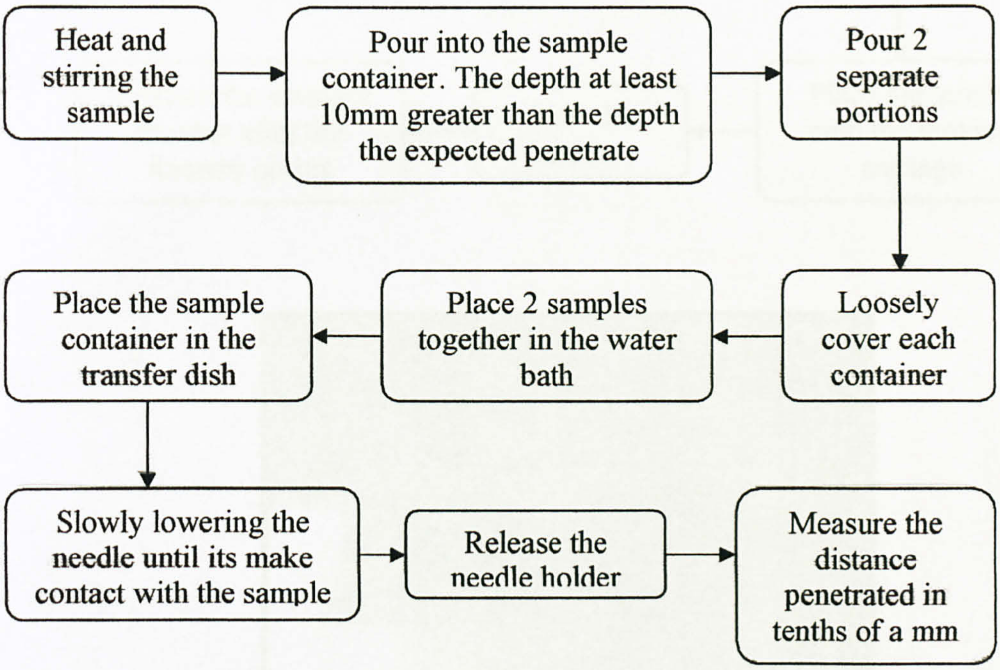


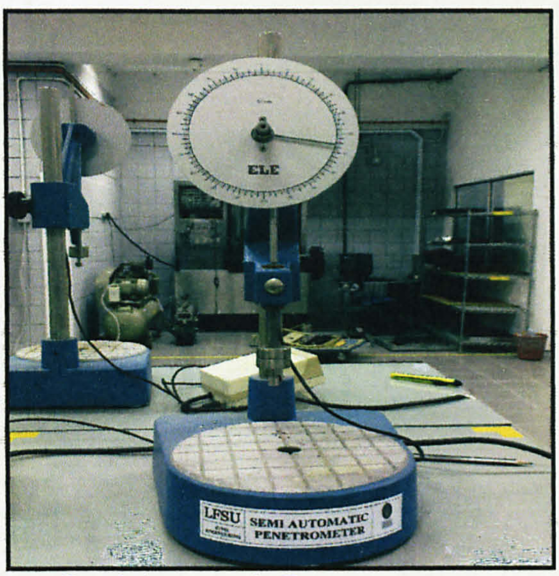
Parameter	Wearing Course	Binder Course	Results (from Graph)	Comment
Stability	>500kg	>450kg	800kg	**Passed**
Flow	>2.0 mm	>2.0 mm	3.50mm	**Passed**
Porosity	3%-5%	3%-5%	4%	**Passed**

Appendix B

Standard Procedure of Characteristics and Performance Testing

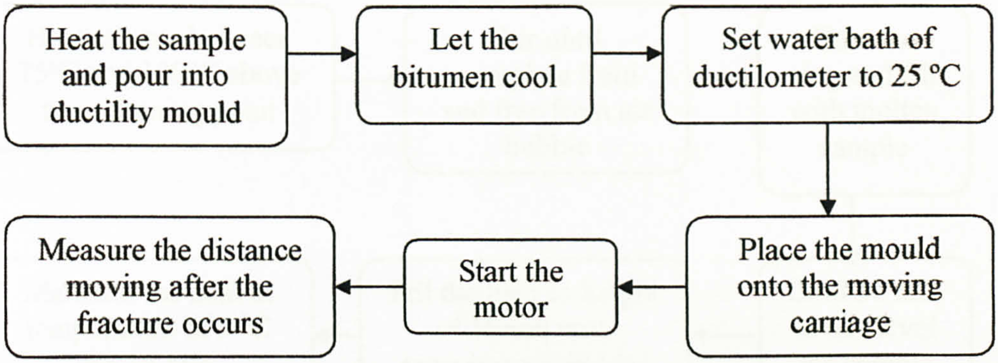
Standard Penetration Test





Semi Automatic Penetrometer

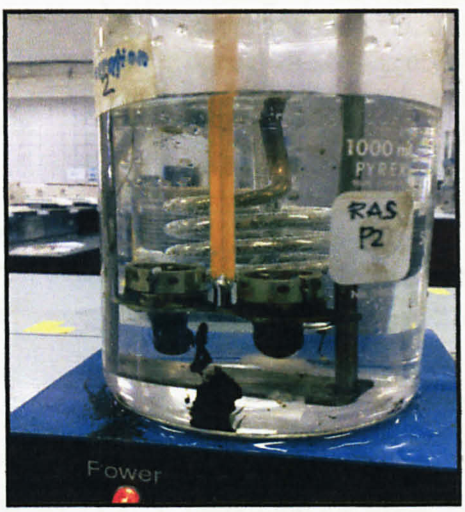
Ductility Test



Ductility Mould

Softening Point Test

1. Heat sample between 75°C and 100°C above the softening point
2. Stir until complete fluid and free from air bubble
3. Heat the ring and fill with molten sample
4. Cool 30 min in air, level the sample
5. Fill the bath to height of 50mm with temperature of 5 °C
6. Maintain the bath at temperature of 5 °C for 15 min
7. Heat the bath and stir the liquid
8. Record for each temperature of ring and ball



Softening Point Test

Specific Gravity and Water Absorption Test (Coarse Aggregate)

Obtain a sample of coarse aggregate material retained on the No. 4 (4.75 mm) sieve (Figure 6). This sample size is based on nominal maximum aggregate size (NMAS).

→ Wash the aggregate retained on the No. 4 (4.75 mm) sieve. This discards small aggregate particles clinging to the retained large particles.

→ Dry the material until it maintains a constant mass. This indicates that all the water has left the sample. Drying should occur in an oven regulated at 230°F (110°C).

→ Cool the aggregate to a comfortable handling temperature.

→ Immerse the aggregate in water at room temperature for a period of 15 to 19 hours

→ Dry the sample to a saturated surface dry (SSD) condition. Rolling up the aggregate into the towel and then shaking and rolling the aggregate from side to side is usually effective in reducing the sample to a SSD condition. It may be necessary to wipe the larger particles separately. Once there are no visible signs of water film on the aggregate particle surfaces, determine the sample mass.

→ Place the entire sample in a basket and weigh it underwater. The basket should be pre-conditioned to the water bath temperature. Shake the container to release any entrapped air before weighing. The container overflow needs to work properly to compensate for the water displaced by the sample.

→ Remove the aggregate from the water and dry it until it maintains a constant mass. This indicates that all the water has left the sample. Drying should occur in an oven regulated at 230°F (110°C).

→ Cool the aggregate in air at room temperature for 1 to 3 hours then determine the mass.

Flakiness and Elongation Test

Sieve a sample of coarse aggregate and collect those particles retained on the specified sieve size(s); usually the 0.375 inch (9.5 mm) or No. 4 (4.75 mm) sieve are specified.

Reduce each specified size fraction until approximately 100 particles are obtained for each specified size fraction.

Checking for flatness OR elongation. Test each of the particles in each of the size fractions and place them into one of three groups: flaky, elongated, or neither flaky nor elongated.

Testing for flakiness. Set the larger opening of the proportional caliper equal to the particle width. The particle is flat if the thickness fits in the smaller opening

Testing for elongation. Set the larger opening of the proportional caliper equal to the particle length. The particle is elongated if the width fits in the smaller opening.

After all particles are tested, determine the proportion of the sample in each group by either count or mass.

Checking for flakiness AND elongation. Use the proportional caliper device to check flaky and elongation of the particles.

Set the larger opening of the caliper equal to the length of the particle. The particle is considered flat and elongated if the particle, when oriented to measure its thickness, can pass completely through the smaller opening of the caliper.

After all particles are tested, determine the proportion of the sample in each group by either count or mass.

Flakiness and Elongation Test

Los Angeles Abrasion Test

Obtain the aggregate sample to be tested, and reduce the sample to adequate size

→ Wash the sample and oven dry to a constant mass at 230°F (110°C).

→ After drying, sieve the material into individual size fractions, and recombine to one of four specified gradings that most nearly represents the aggregate gradation as received

→ Record the total sample mass. The total sample mass should be about 5000g

→ Place the sample and the specified number of steel spheres into the drum and rotate for 500 revolutions at 30 to 33 rev/min

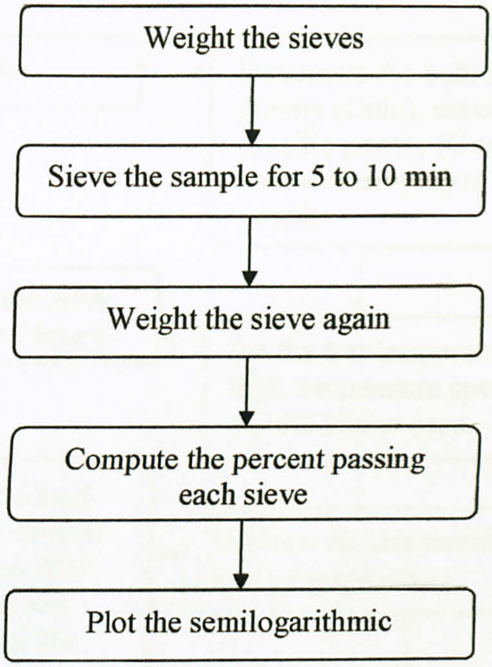
→ Discharge the material and sieve the aggregate over a sieve coarser than a 1.70-mm

→ Sieve the finer material on a No. 12 (1.70 mm) sieve.

→ Wash the aggregate coarser than the No. 12 (1.70 mm) sieve and oven-dry to a constant mass at 230°F (110°C). After cooling, determine the mass

During LA Abrasion Test

Sieve Analysis Test



Stack of Sieve in a Mechanical Sieve Shaker

Wheel Tracking Test

Prepare the sanple

→ Determine the bulk specific gravity (Gmb), maximum specific gravity (Gmm) and air void content (Va) of each sample.

→ Set the test temperature at the high temperature specification of the PG binder used.

→ Preheat the samples in the APA or a calibrated oven for 6 hours.

→ Set the hose pressure and load cylinder pressure to the desired levels. Typically, 120 psi (827 kPa) is used for the hose and 120 lb (534 N) is used for the load.

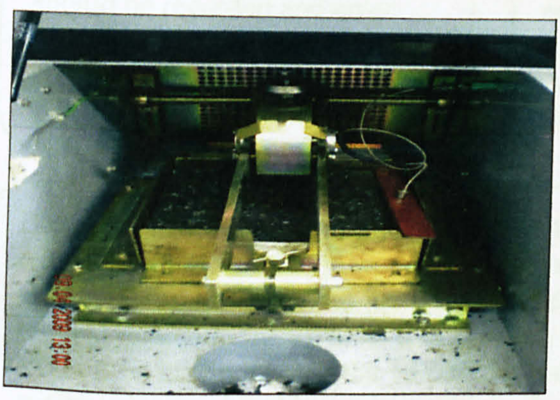
→ Stabilize the test chamber at the desired temperature.

→ Insert the test samples into the chamber.

→ Zero the gauge and take initial rut depth readings

→ Start the loading.

→ At the end of 8,000 cycles, repeat step 10 to get the final rut depth measurement



Wheel Tracking Machine

Wheel Tracking Machine setup

Beam Fatigue Test

Obtain a test beam by sawing at least 0.25 inches (6 mm) from both sides of a compacted HMA specimen. The final dimensions should be 15 inches (380 mm) length by 2 inches (50 mm) height by 2.5 inches (63 mm) width

Prepare three replicate beams. If these are laboratory-prepared or loose field samples, compact them in accordance with AASHTO PP 3 or ASTM D 3202.

Measure the height and width of each beam to the nearest 0.0004 inch (0.01 mm) at three points along the middle 4 inches (100 mm) of the beam and determine the average for each dimension.

Condition the beams at the test temperature (typically 68°F (20°C)) for two hours 5. Open clamps and slide specimen into position. Close outside clamps first, then inside clamps with enough pressure to hold the specimen in place

Position the LVDT onto the specimen such that the LVDT displacement reading is close to zero.

Allow sample to rest for 10 minutes to relax any residual stresses caused by loading.

Select an initial strain (250 – 750 microstrain), loading frequency (5 – 10 Hz), and interval at which the results should be recorded and enter them into the control components of the test program.

Apply 50 load cycles and determine the beam stiffness at the 50th cycle. This will be recorded as the initial stiffness of the beam.

Select a strain level that will provide an estimated 10,000 load cycles before the initial stiffness is reduced to 50 percent or less.

Begin the test. Test results should be monitored and recorded at the selected load cycle intervals and the test should be terminated when the beam has reached a 50 percent reduction in stiffness. It is possible that very low strain tests may not reach the 50 percent reduction in stiffness in a reasonable amount of time. In this case a maximum number of cycles should be specified as the termination point of the test.

Positioning beam fatigue sample