The Effect of Different Filler Materials and Gradation on Rutting and Cracking of Bituminous Mixture

by

Ili Ayuni binti Johan

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CERTIFICATION OF APPROVAL

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Civil Engineering Programme
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Approved by,

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UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

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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.

ILI AYUNI BINTI JOHAN

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ABSTRACT

Different filler materials and gradation can change the bituminous performance in pavement. Filler materials act to improve the quality of mastic. Meanwhile, gradation can change the mechanical behaviour of bituminous mixture. Types of fillers that are used in this experiment are Ordinary Portland Cement (OPC), Pulverised Fly Ash (PFA), and Hydrated Lime. Two types of gradation are well-graded and gap-graded. This gave six different asphaltic concrete combinations where a series of testing are done to evaluate the characteristics of each bituminous mixture. Various test on the aggregate gradation, aphalt material and mineral filler are done before the Marshall Test in determining the best oil content. It was followed by the WESSEX Wheel Tracking Test, Beam Fatigue Test, Indirect Tensile Fatigue Test and Creep Test where the outcome are analyzed to determine which combination of filler and gradation relatively give better performance in reducing the occurrence of rutting and cracking. It shows that the combination of lime and well graded produced adequate void rate and flexibility, higher stability, lower rutting deformation rate, higher stiffness, and longer fatigue life.

Keywords : Bituminous mixture, filler, gradation, rutting, cracking, WESSEX Wheel Tracking Test, Beam Fatigue Test, Indirect Tensile Fatigue Test , Creep Test.

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ABBREVIATIONS AND NOMENCLATURES

ASTM	:	American Society for Testing and Materials
AASHTO	:	American Association of State Highway and Transport Officials
AC20	:	Asphaltic Concrete with NMAS of 20mm
AIV	:	Aggregate Impact Value
BS	:	British Standard
HMA	:	Hot Mix Asphalt
JKR	:	Jabatan Kerja Raya (Public Works Department)
MS	:	Malaysian Standard
OBC	:	Optimum Bitumen Concrete
OPC	:	Ordinary Portland Cement
PFA	:	Pulverised Fly Ash
PG	:	Penetration Grade
SEM	:	Scanning Electron Microscope
VMA	:	Voids in Mineral Aggregate
XRD	:	X-ray Diffraction

CHAPTER 1

INTRODUCTION

1.1 Background

The components of a flexible road are the wearing course, the base course and subgrade. The function of the wearing course is to provide a waterproof, non-skid cover to the road and withstand the shear and abrasive action of traffic. It may consist of only a very thin layer of bituminous material for a lightly trafficked road or several inches of high quality bituminous mixture for heavy traffic.

The function of the base is to carry the traffic load. It is made up of a number of layers materials of different strength. In modern road construction, it is increasingly common to build a large part of the base with bitumen bound material.

Aggregates used in making road mixes include broken stone of various sizes, crushed slag, gravel and sand. For certain mixes, filler is also sometimes added. Filler is classified as finely ground material that passes through sieve No.200 or sieve size 75μm. (Garber and Hoel, 2002).

Fillers are added to asphalt binders to change mixture behavior, primarily to enhance the roadway performance characteristics of bituminous mixtures. The advantages that filler offers for the durability of the bituminous mixtures in the case of water action are due, in principle, to its physical characteristics, which reduce the porosity of the granular structure and thereby make access by water and air difficult. Moreover, the chemical nature of filler may mean greater affinity with the asphalt binder, which can improve resistance to the displacement that water causes the bitumen.

Gradation is the distribution of aggregate particle sizes for a given blend of aggregate mixture. The grading of aggregate is one of great importance in designing of road mixes. The large stone forms the main structure, the interstices being filled with smaller stone, sand and filler, the whole being bound together with bitumen to give a compact durable construction.

1.2 Problem Statement

The main problem road users usually faced is pavement damage. It is caused by the effects of traffic flow, thermal variation, and water erosion. Therefore, how to maintain or improve the structure and reliability of the road system is a crucial issue, which may benefit not only road users but also be economically beneficial.

As Malaysia is located in the tropical region, high temperatures in addition to the impediments of overweight loading and heavy rainfall contribute to frequent road surface deformation and damage. It can be said that water erosion is the main reason in to weaken cohesive force between asphalt mortar and aggregates and finally result in the rutting and cracking of the asphalt concrete.

Rutting and fatigue cracking are two types of pavement damage that often occurs in this country due to the hot climatic condition. Rutting is a structural damage which has the longitudinal depression in the wheel path after repeated application of axle loading. Fatigue cracking results from cyclic stresses that are below the ultimate tensile stress, or even the yield stress of the material.

Different types of filler and gradation will give different performances either in stability or other aspects. Thus, there was a needed to conduct an experimental laboratory to investigate the effect of difference filler materials and gradation affecting rutting and cracking in order to improve the performance of the bituminous mixture.

1.3 Objectives

The objectives of this study were to evaluate:

- The effect of filler material and gradation on rutting and cracking in bituminous mixture.
- The possibility of using different locally available and low cost materials as filler to reduce the occurrence of surface distress on pavements.
- The findings of the result and draw conclusions and recommendations.

1.4 Scope of Study

The objectives of this study covered the following tasks:

- Review the literature to determine the effects of the filler and gradation on the rutting and cracking.
- Determine the properties of optimum binder content of HMA for each variation.
- Conduct laboratory test for mixture designs of HMA for each variation.
- Determine the engineering properties of HMA mixtures for each variation.
- Make highlight the conclusions based on the results and provide recommendations on the effect of different filler material and gradation affecting rutting and cracking and on further research that may be needed to enhance hot mix asphalt mixture properties.

The mix parameters include three types of mineral filler and two types of aggregate gradation.

In this study, the three types of mineral filler that will be used are Ordinary Portland Cement (OPC), Pulverised Fly Ash (PFA), and Hydrated Lime. Two types of aggregate gradations are well graded and gap graded. Well graded or also known as dense graded refers to a gradation that is near maximum density. Gap graded refers to a gradation that contains only a small percentage of aggregate particles in the mid-size range. The curve is near-horizontal in the mid-size range. These mixes can be prone to segregation during placement.

The laboratory tests significance with rutting and cracking was performed on the optimum bitumen content of each mixes. The tests are Wheel Tracking Test, Creep Test, Indirect Fatigue Test, and Beam Fatigue Test.

CHAPTER 2

LITERATURE REVIEW

2.1 Filler

Filler is a fine dust used to harden the asphalt cement, and improve adhesion of the asphalt cement to the aggregates. Properties of mineral filler have a significant effect on the properties of the HMA mixtures where it is shown from numerous studies.The return of most of the fines to the HMA mixture is encouraged by the introduction of environmental regulations and the subsequent adoption of dust collection system (baghouse). Many agencies used a maximum filler/asphalt ratio of 1:2 to 1:5 based on weight to limit the amount of the minus 200 material. Their influence on the properties of HMA mixtures also varies since the fines vary in gradation, particle shape, surface area, void content, mineral composition, and physico-chemical properties (Kandhal, 1981).

2.1.1 Hydrated Lime

Hydrated lime is a modifier that improves performance in multiple ways. Hicks and Scholz stated that modifications made to hot mix asphalt with hydrated lime will add years to its life. Pavement damages such as stripping, rutting, cracking, and aging can be reduced from these modifications (Little and Epps, 2001). Hydrated lime substantially improves each of these properties when used alone, and also works well in conjunction with polymer additives, helping to create pavement systems that will perform to the highest expectations for many years. Lime is also cost effective from the life cycle cost analysis (Hicks and Scholz, 2001).

2.1.1.1 Hydrated Lime Improves Stiffness and Reduces Rutting

The ability of hydrated lime to make an asphalt mix stiffer, tougher, and resistant to rutting, is a reflection of its superior performance as an active mineral filler. Rutting is permanent deformation of the asphalt, caused when the elasticity of the material is exceeded. Hydrated lime significantly improves the performance of asphalt in this respect. Unlike most mineral fillers, lime is chemically active rather than inert. It reacts with the bitumen, removing undesirable components at the same time that its tiny particles disperse throughout the mix, making it more resistant to rutting and fatigue cracking.

The stiffening that results from the addition of hydrated lime can increase the penetrarion grade (PG) rating of an asphalt cement. Depending upon the amount used (generally 10 to 20% by weight of asphalt) the PG rating may increase by one full grade. In other words, a PG 64-22 can be increased to a PG 70-22. The addition of the lime will not, however, cause the mix to become more brittle at lower temperatures. At low temperatures the hydrated lime becomes less chemically active and behaves like any other inert filler (Little and Epps, 2001).

2.1.1.2 Hydrated Lime Reduces Cracking

Hydrated lime reduces asphalt cracking that can result from causes other than aging, such as fatigue and low temperatures. Although, in general, stiffer asphalt mixes crack more, the addition of lime improves fatigue characteristics and reduces cracking. Cracking often occurs due to the formation of microcracks. These microcracks are intercepted and deflected by tiny particles of hydrated lime. Lime reduces cracking more than inactive fillers because of the reaction between the lime and the polar molecules in the asphalt cement, which increases the effective volume of the lime particles by surrounding them with large organic chains (Lesueur and Little, 1999). Consequently, the lime particles are better able to intercept and deflect microcracks, preventing them from growing together into large cracks that can cause pavement failure.

2.1.2 Pulverised Fly Ash

Fly ash is most common waste material used in worldwide. Fly ash is a kind of coal combustion byproduct (CCBs), i.e. an inorganic residue that remains after pulverized coal is burned. The use of fly ash as a pavement material is assumed to able to conserve energy by reducing the demand for typical pavement materials such as lime, cement and crushed stone, that take energy to produce. More barrels of oil can be save is one of the advantage using PFA as a filler. The sequence is it reducing the production of greenhouse gases that contribute to global warming (Majko, 2004).

Another advantage stated by Setiadji (2005) of the use of fly ash in pavement construction is easy to obtain and no need special treatment before being used.

2.2 Gradation

The distribution of particle sizes in an aggregate is known as its gradation. Roberts and friends (1996) stated that stiffness, stability, durability, permeability, workabilty, fatigue resistance, frictional resistance and resistance to moisture damage in HMA are determined by gradation. Therefore, most agencies specify allowable aggregate gradations since it is a primary concern in HMA mix design. For this research, well graded and gap graded are used as the parameter. Both gradation distribution are in Figure 2.1.

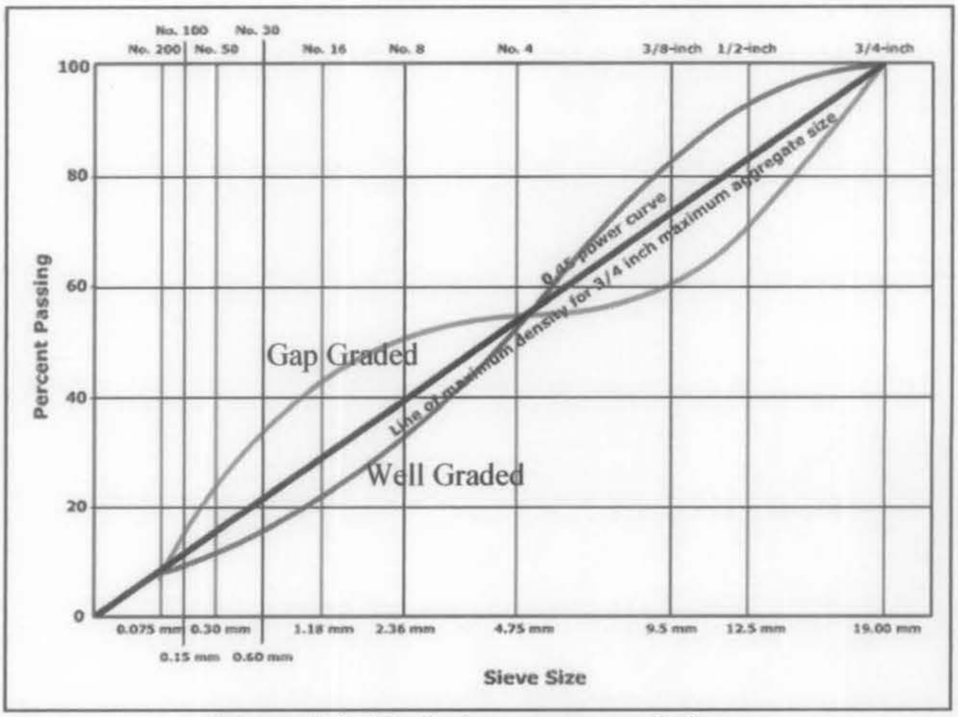

Figure 2.1 : Typical aggregate gradations

Coarse materials that are well-graded are usually preferable for bearing from an engineering standpoint, since good gradation usually results in high density and stability. Specifications for controlling the percentage of the various grainsize groups required for a well-graded soil have been established for engineering performance and testing. By proportioning components to obtain a well-graded soil, it is possible to provide for maximum density. Such proportioning develops an "interlocking" of particles with smaller particles filling the voids between larger particles, making the soil stronger and more capable of supporting heavier loads. Since the particles are "formfitted", the best load distribution downward will be realized. When each particle is surrounded and "locked" by other particles, the grain-to-grain contact is increased and the tendency for displacement of the individual grains is minimized (U.S Army).

2.2.1 Well Graded

A well-graded soil is defined as having a good representation of all particle sizes from the largest to the smallest (see Figure 2.2), and the shape of the grain size distribution curve is considered "smooth."

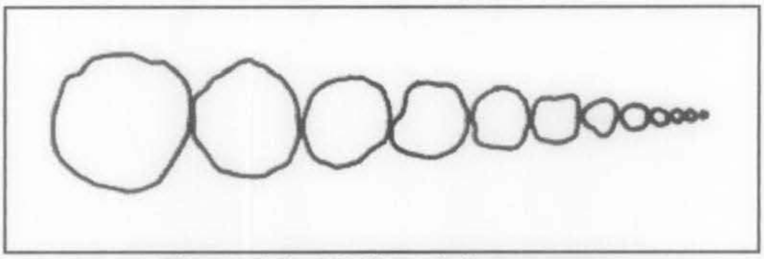

Figure 2.2 : Well graded aggregate

2.2.2 Gap Graded

A gap-graded soil contains both large and small particles, but the gradation continuity is broken by the absence of some particle sizes (see Figure 2.3).

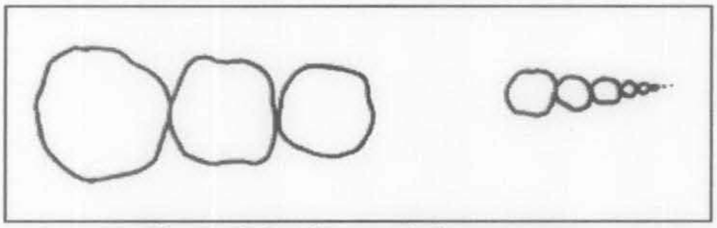

Figure 2.3 : Gap graded aggregate

2.3 Rutting

Campen *et al.*(1961) investigated 18 resurfacing projects in the city of Omaha, Nebraska. The rutting (Figure 2.4) and shoving occurred where traffic was channelized and in turns or the bus stops. They reported that the voids in the mineral aggregate (VMA) were low in their mixes because of a very dense gradation, and this made the performance of asphalt wearing surfaces on the border line. They stated, "Either we might get a little shoving and rutting or else the rate of wear might be higher than desired."

Figure 2.4 : Rutting from mix instability

Asphalt technologist have long since considered bitumen as being a viscoelastic material, implying that it had the dual functions of being viscous (it could flow under an applied load) and of being elastic (it could tend to recover its previous form when the applied load was removed). Temperature and rate of loading affect the viscous and elastic behaviour. The addition of filler with appropriate gradation will produce a binder with significantly better resistance to rutting than unmodified bitumens (Little and Epps, 2001).

Problem that may occur due to rutting is it can be hazardous to the road user because ruts tend to pull a vehicle towards the rut path as it is steered across the rut. Apart from that, ruts filled with water can cause vehicle hydroplaning.

2.4 Cracking

Fatigue cracking is a series of interconnected cracks caused by fatigue failure of the HMA surface (or stabilized base) under repeated traffic loading. cracking will propagates to the surface as one or more longitudinal cracks after initiates at the bottom of the HMA layer where the tensile stress is the highest in thin pavements. This type of damage is referred to as "bottom-up" or "classical" fatigue cracking. Different with thick pavements, the cracks most likely initiate from the top areas of high localized tensile stresses resulting from tire-pavement interaction and asphalt binder aging (top-down cracking). A pattern resembling the back of an alligator or crocodile such in Figure 2.5 is developed when the longitudinal cracks connect forming many-sided sharp-angled pieces after repeated loading.

Figure 2.5 : Bad fatigue cracking

Cracking is the indicator of structural failure, where it may contribute to further deteriorate to a pothole. The reason is because cracks allow moisture infiltration and roughness.

CHAPTER 3

METHODOLOGY

3.1 Introduction

A series of experiments according to ASTM and AASHTO must be performed to determine which combination of filler and gradation has a better performance in preventing rutting and cracking. In this case of study, other than three different types of filler and two types of aggregate gradation, it also include the usage of asphalt material. The three types of filler that were chosen to represent this study are Ordinary Portland Cement (OPC), Pulverised Fly Ash (PFA), and Hydrated Lime. Meanwhile the different types of gradation include well graded and gap graded.

All materials are to be prepared in accordance with the Standard Specification for Roadworks published by JKR (JKR/SPJ/1988). All the tests were conducted at Universiti Teknologi Petronas' Highway Lab. The general procedures for laboratory work are illustrated in Figure 3.1.

3.2 Gradation Aggregate

Types of coarse aggregate used is granite and river sand for fine aggregate. There are five tests for aggregates portion which include:

- Sieve Analysis (Dry Sieve Analysis)
- Specific Gravity Test
- Water Absorption Rate Test
- Los Angeles Abrasion Test
- Aggregate Impact Value (AIV)

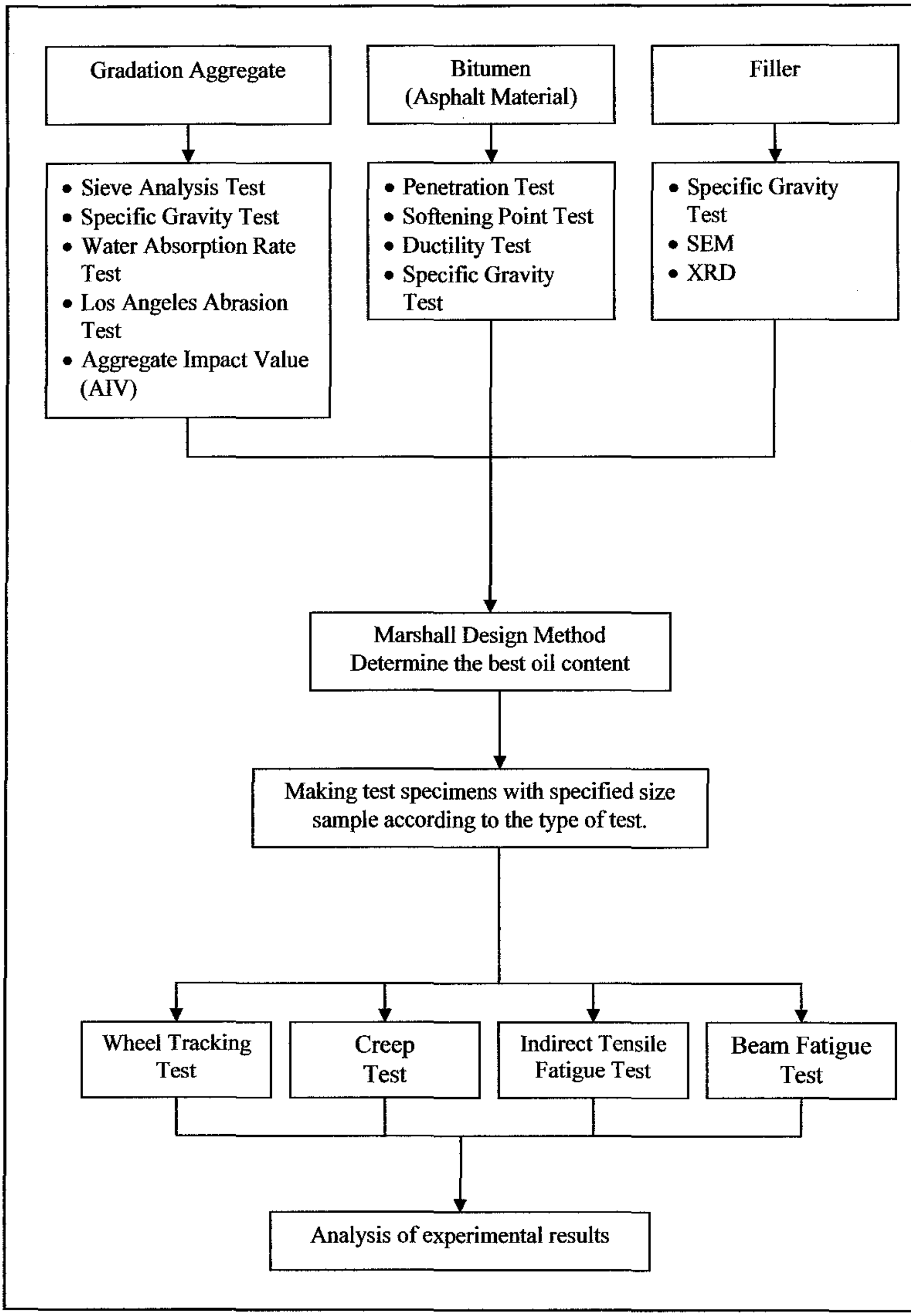

Figure 3.1 : Flow diagram for laboratory analysis process

The coarse aggregate conformed to the requirements – the Los Angeles Abrasion Value shall not be more than 25% (ASTM C 131), and water absorption shall not be more than 2% (MS30).

Fine aggregate consists of river sand. Fine aggregate conformed to the requirements – sand equivalent of aggregate fraction passing the 4.75mm sieve shall be not less than 45% (ASTM D 2419), and the water absorption shall not be more than 2% (MS 30).

3.2.1 Sieve Analysis Test

Determination of the particle size distribution of fine and coarse aggregates by sieving. In this case of study, the well graded is based on JKR/SPJ/1988 and gap graded is based on British Standard. Type of aggregate used for coarse is granite and for fine is sand. The dry sieve analysis was performed to separate the aggregates according to the sieve sizes used in the gradation so as to make it easier to batch the mixes. The gradation of each mix are following the result from the research done by previous postgraduate student.

The procedures for dry sieve analysis are as follow:

(i) The sieves were arrange in order of decreasing size of opening from top to bottom on the sieve shaker.
(ii) The aggregate were placed on the top sieve and started sieving.
(iii) Aggregate that have been sieved were separated according to the size.
(iv) For mixing, total aggregate of different sizes as designed were weighed.

The Specification Limits of aggregate for both gradation are in *Appendix A*.

3.2.2 Specific Gravity Test

Determine the bulk, apparent, and effective specific gravities. The effective specific gravity was determined since the absorption of asphalt cement is an important factor in asphalt mixtures.

3.2.3 Water Absorption Rate Test

Determine the absorption of coarse and fine aggregates. Absorption is the process by which water is drawn into and tends to fill the permeable pores in a porous solid body.

3.2.4 Los Angeles Absorption Test

The test is to determine the ability of coarse aggregate smaller than 37.5mm (1-1/211) to resist abrasion, using the Los Angeles Testing Machine.

3.2.5 Aggregate Impact Value (AIV) Test

The aggregate impact value is a strength value of an aggregate that is determined by performing the Aggregate Impact Test on a sample of the aggregate in question.

Basically the AIV is the percentage of fines produced from the aggregate sample after subjecting it to a standard amount of impact.

The standard amount of impact is produced by a known weight, i.e. a steel cylinder, falling a set height, a prescribed number of times, onto an amount of aggregate of standard size and weight retained in a mould.

Aggregate Impact Values, (AIV's), below 10 are regarded as strong, and AIV's above 35 would normally be regarded as too weak for use in road surfaces.

Aggregate Impact Values and Aggregate Crushing Values are often numerically very similar, and indicate similar aggregate strength properties.

3.3 Bitumen

Bituminous binder used for this research for asphaltic concrete was bitumen of penetration grade 80-100. For this study, four tests are performed on bitumen:

- Penetration Test
- Softening Point Test
- Ductility Test
- Specific Gravity Test

3.3.1 Penetration Test

Bitumen is manufactured in a wide range of grades for different applications. Each grade is numbered according to its resistance to penetration. A standard needle is used to measure the penetration under specified conditions of heat pre-treatment, loading, time and temperature.

3.3.2 Softening Point Test

The softening point of bitumen is determined using the Ring and Ball Apparatus to measure the temperature at which the bitumen reaches a certain degree of softness. This test is carried out by placing a steel ball upon a brass ring filled with bitumen and suspended in water or glycerine bath. The bath temperature is raised at a specified rate and the temperature at which the bitumen softens sufficiently to allow the ball to fall a specified distance is noted.

3.3.3 Ductility Test

A standard sample of asphaltic material will stretch before breaking when tested on standard ductility test equipment at 25°C (77°F) where the distance in centimeters is called ductility. The result of this test indicates the extent to which the material can be deformed without breaking. Although the exact value of ductility is not as important as the existence or nonexistence of the property in the material, this is an important characteristic for asphaltic materials (Garber and Hoel, 2002).

3.3.4 Specific Gravity Test

This test is based on Standard Test Method for Density of Semi-Solid Bituminous Materials (Pycnometer Method) – ASTM Designation : D70 - 03. The values of density are used for converting volumes to unit of mass, and for correcting measured volumes from the temperature of measurement to a standard temperature using Practice D 4311.

3.4 Filler

For this study, three types of filler are used. It consist of Ordinary Portland Cement, Pulverised Fly Ash, and Hydrated Lime. Three tests are done to differentiate the characteristic of each filler:

- Specific Gravity Test
- Scanning Electron Microscope (SEM)
- X-ray Diffraction (XRD)

3.4.1 Specific Gravity Test

Determine the bulk, apparent, and effective specific gravities. The effective specific gravity was determined since the absorption of asphalt cement is an important factor in asphalt mixtures.

3.4.2 Scanning Electron Microscope Test (SEM)

The scanning electron microscope (SEM) is a type of electron microscope that images the sample surface by scanning it with a high-energy beam of electrons in a raster scan pattern. The effect of shape for different type of filler can be study through this test.

3.4.3 X-ray Diffraction (XRD)

X-ray diffraction (XRD) is a versatile, non-destructive technique that reveals detailed information about the chemical composition and crystallographic structure of natural and manufactured materials.

3.5 Marshall Mix Design

The Marshall Method for hot-mix asphalt concrete mix design is a rational approach to selecting and proportioning two materials, asphalt cement and mineral aggregates to obtain the specified properties in the finished asphalt concrete surfacing structure. The method is intended for laboratory design of asphalt hot-mix paving mixtures.

For this case study, after the optimum percentage of bitumen content is obtained, the mixing process can be done. Bituminous mixture with different type of filler and gradation will be tested for rutting and cracking determination tests at optimum percentage of bitumen content.

3.6 Wheel Tracking Test

In the Dry Wheel Tracker, shown in *Appendix B*, a loaded wheel is run over an asphalt sample in a sealed and insulated cabinet for 45 minutes. The device applies a 520N vertical force through 50 mm wide steel wheel with a 12.5 mm thick rubber contact surface. It has a dual wheel assembly that accommodates testing two specimens simultaneously.

A specially designed computer program controls the operation of the machine, and records rut depth, temperature and elapsed time during the test. The computer interface allows the user to plot rut depth versus time via displacement instrumentation on each loaded wheel. SGC samples are placed inside wooden sample holders and mounted on a reciprocating platform that translates a horizontal distance of 230 mm. The rate of loading is 26 cycles per minute, which corresponds to 52 wheel passes per minute. Since the height of test specimens is expected to vary by ±5 mm, plaster of Paris is used to fill the small void below each specimen and provide a uniform base for the wooden molds after the test specimens have been installed. Loading is performed inside a heat-regulated cabinet that is temperature controlled with input from thermocouples mounted in holes drilled in the tops of test specimens. The Wheel Tracker test offers a simple and inexpensive method of predicting rutting. An Immersion Wheel Tracker and a Slab Compactor are also available at Wessex. However, there is not any field data available at the time this report was prepared to validate its accuracy in predicting performance (Brown *et al.,* 2001).

3.7 Creep Test

The creep test (unconfined or confined) has been used to estimate the rutting potential of HMA mixtures (Brown *et al.,* 2001). This test is conducted by applying a static load to a HMA specimen and measuring the resulting permanent deformation .

The creep test for unconfined must be performed at relatively low stress levels (cannot usually exceed 30 psi (206.9 kPa)) and low temperature (cannot usually exceed 104°F (40°C)), otherwise the sample fails prematurely. The test conditions consist of a static axial stress, F, of 100 kPa being applied to a specimen for a period of 1 hour at a temperature of 40/C. This test is inexpensive and easy to conduct but the ability of the test to predict performance is questionable.

3.8 Indirect Tensile Fatigue Test

The indirect tensile (IDT) testing mode was chosen to characterize the mixtures from their dynamic modulus, fatigue lives under controlled-force conditions, and permanent deformation potential. The procedures described follow those suggested by Kim *et al.* (2004).

The Gyratory Compactor compacted samples of 100mm diameter and approximately 70mm height with 1,200g of mixture.

The gauge points were placed as accurate as possible to the desired locations of the specimen to alleviate positioning errors. Towards the end, a gauge point mounting and gluing device, was developed and used. Lateral metallic bars were also used to avoid rotation and translation at the top and bottom plates while gluing the gauge points.

The gauge length used to mount the extensometers for measuring displacements was 25.4mm. After gluing the gauge points and attaching the extensometers in both sides of the specimen, the specimen was placed between loading strips that were held together by two cylindrical bars. The specimens were then placed into the environmental chamber of the UTM-25kN for the temperature conditioning required for each test. The range of temperatures that can be controlled by the environmental chamber is between -15°C and 60°C.

Generally in Malaysia, the temperature usually reach 40°C. Due to this fact, the testing temperature chosen to characterize the fatigue lives of the mixtures was 40°C. The testing frequency chosen was 10Hz which is approximately equivalent to a vehicle speed of 50mph (Huang, 2004). The horizontal deformation, parallel to the axis of tensile stress, was monitored and used to determine the failure of the specimens. This was based on the concept that fatigue damage generally occurred when high levels of tensile strains at the bottom of the HMA layer created cracks that propagated upward towards the surface (Brown *et al.*, 2001). Failure was considered to occur when the constant rate of increase of the horizontal deformations was replaced by a faster rate of increase of the deformations. After that point, the microcracks present in the specimen were combined into macrocracks and the specimen was broken into two pieces.

3.9 Beam Fatigue Test

The fatigue cracking test resistance of the asphalt mixtures was determined using the Flexural Beam Fatigue Test. This test is executed on a beam asphalt (50mm x 63 mm x 380mm) by applying a repeated sinusoidal loading (10Hz) subjecting the specimen to four-point bending with free rotation and horizontal translation at all load and reaction points. The test is performed under controlled strain conditions at a reference temperature (in this case, 40°C). The test is continued until the stiffness of the asphalt mixture is reduced to 25% of the initial stiffness or 500,000 cycles are completed. The number of cycles to this reduction in stiffness occurs is known as the fatigue life, or cycles to failure. Testing will be conducted on triplicate specimens using one strain level (300 microstrains).

3.10 Health and Safety

While performing all the tests, the safety awareness is very important. As tests on bitumen are the most severe, precautions need to be practiced. Below is safety and handling of bulk bitumen:

STORAGE

1. 80/100 Penetration Grade is normally stored at 150°C. Maximum temperature should not exceed 200°C.
2. Overheating bitumen beyond 225°C presents fire risk.
3. Water in contact with hot bitumen leads to frothing causing pumpability problems.

SAFETY MEASURES

1. Heat bitumen up to the specified temperature.
2. Avoid hot bitumen getting into contact with water.
3. Use good conditioned hose and pipes. Check hoses and joints frequently.
4. Use clothing and gloves when unloading bitumen from tanker.
5. Never extinguish a bitumen fire with water.

FIRE FIGHTING

1. Switch off burner or oil heater.
2. Switch off pumps and close delivery valves.
3. Use fire extinguisher or sand to put off fire.

SAFETY KIT

1. Always maintain first aid kit at convenient place.
2. Severe burns have to be treated at the hospital.
3. Slight skin burn should be removed by the doctor. Slight bitumen splashes can be softened with cod liver oil.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The methodology used for this study has been discussed in Chapter 3. Results of each procedure in determining the properties are presented in this chapter and will be further analysed and discussed in depth.

4.2 Results of Tests Conducted on the Materials

Specific results are attached in *Appendix C*.

4.2.1 Coarse Material

Coarse aggregate used are angular in shape and free from dust, clay, vegetative and any other organic matter, and other deleterious substances.

Table 4.1 : Result on Characteristic Tests for Coarse Aggregate

Test	Result
Specific Gravity	2.56
Water Absorption Rate Test	0.83%
LA Abrasion	18%
Aggregate Impact Value	23.9%

All the results in Table 4.1 are following the specificatons published by JKR (JKR/SPJ/1988). Thus the aggregates can be used for further experiment.

4.2.2 Fine Material

Fine aggregates used are clean river sand, which free from clay, loam, aggregations of material, vegetative and other organic matter, and other deleterious substances.

Table 4.2 : Result on Characteristic Tests for Fine Aggregate

Test	Result
Specific Gravity	2.55
Water Absorption Rate Test	0.51%

All the results in Table 4.2 are following the specificatons published by JKR (JKR/SPJ/1988). Thus the aggregates can be used for further experiment.

4.2.3 Bitumen

Penetration grade for bitumen used in this study are conforming to M.S. 124, 80-100 grade. The results in Table 4.3 shows that the other characteristic tests for the bitumen are adequate for experimental usage.

Table 4.3 : Result on Characteristic Tests on Bitumen

Test	Result
Specific Gravity	1.026
Softening Point	48.3°C
Ductility	116.9cm
Penetration grade	80/100

4.2.4 Filler

Tests on filler are done to study the physical and chemical properties of each filler. At the time of mixing with bitumen it shall be sufficiently dry to flow freely and shall be essentially free from agglomerations.

4.2.4.1 Specific Gravity

Table 4.4 : Result on Specific Gravity Test for Filler

Type of Filler	Average Density (g/cc)
Ordinary Portland Cement	3.3227
Pulverised Fly Ash	2.8433
Hydrated Lime	2.7487

Lighter unit weight of Hydrated Lime means that it have larger fineness particle. This characteristic will help to fill in the void of asphalt mortar (Refer to Table 4.4).

4.2.4.2 Scanning Electron Microscope (SEM)

The results are in *Appendix D*. Through this test, it is shown that different filler material have diffent shape, size, and surface roughness. This physical criteria affect the performance of the filler when working with different type of gradation. Ordinary Portland Cement particles are geometrical and circle in shape. Pulverised Fly Ash have spherical particle in shape and smooth surface. Meanwhile, hydrated lime particles are the finest and have the most rough surface and only geometrical in shape. This characteristic can be relate to the results for the performance on rutting and cracking.

4.2.4.3 X-Ray Diffraction (XRD)

Table 4.5 : Mineral Composition in Filler from XRD Test

Type of Filler	Main Chemical Composition
Ordinary Portland Cement	Calcium Oxide (CaO), Magnesium Oxide (MgO), Aluminum Oxide (Al_2O_3), Silicate Oxide(SiO_2).
Pulverised Fly Ash	Quartz (SiO_2) and Periclase (MgO).
Hydrated Lime	Portlandite ($Ca(OH)_2$) and Calcium Carbonate ($CaCO_3$).

The full results of test conducted are on *Appendix D*. Evaluating the XRD patterns, several distinct peaks were observed and the above minerals (Table 4.5) are identified. From this test, we can relate it with the pozzolanic activity. Pozzolanic activity is its ability to react with calcium hydroxide in the presence of water to form hydrates possesing cementitious properties. Portlandite is the main chemical composition of hydrated lime, which it is the major bonding agent in cement and concrete. This relation shows why hydrated lime have the highest strength among the three fillers.

4.3 Marshall Test

Table 4.6 : Result on Marshall Test to Determine Optimum Bitumen Content

Filler	Gradation	OBC (%)	Density (g/cm^3)	Porosity (%)	VMA (%)	Stability (kN)
OPC	Well	5.55	5.60	5.60	5.50	5.50
	Gap	6.80	7.10	6.10	7.00	7.00
Fly Ash	Well	5.28	6.50	5.12	4.50	5.00
	Gap	6.77	7.00	6.06	7.00	7.00
Lime	Well	5.46	6.50	5.60	5.10	4.65
	Gap	6.40	6.60	6.09	6.50	6.42

Combination of fly ash and well graded gave the lowest OBC and the highest OBC is from the combination of OPC and gap graded. The above result (Table 4.6) also show that gap graded need higher oil content than well graded. Therefore, it can be said that well graded is better in order to reduce the cost since less oil content is needed.The value of OBC for each combination will be used to prepare samples for rutting and cracking tests.

4.3.1 Density (Unit Weight)

Usually, the higher the unit weight, the longer the life of asphalt concrete pavement. The curves in Figure 4.1 showed that the fly ash in both gradation exhibits a higher unit weight and the highest value occurred at 6.5% for well graded and 7.0% for gap graded of asphalt content. For durable and economical concerns, fly ash seems a better choice, but the difference is small for long term usage.

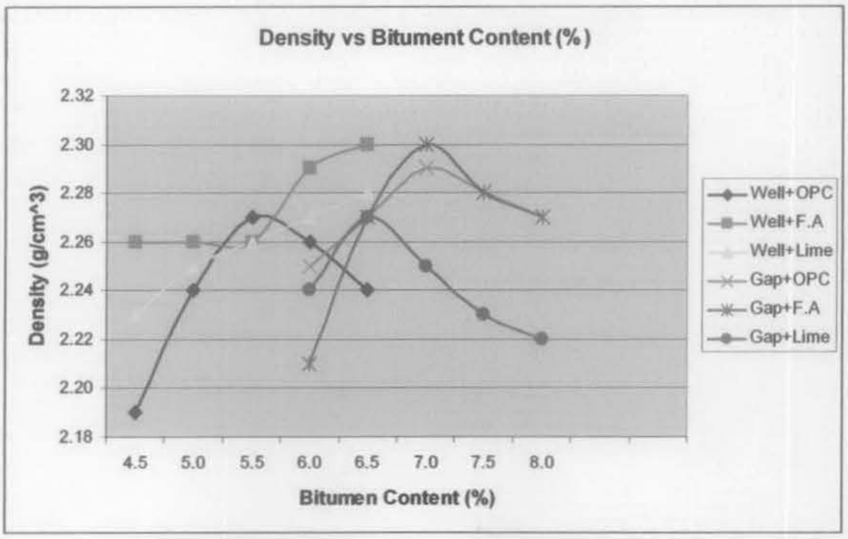

Figure 4.1 : Density vs. Bitumen Content

4.3.2 Porosity

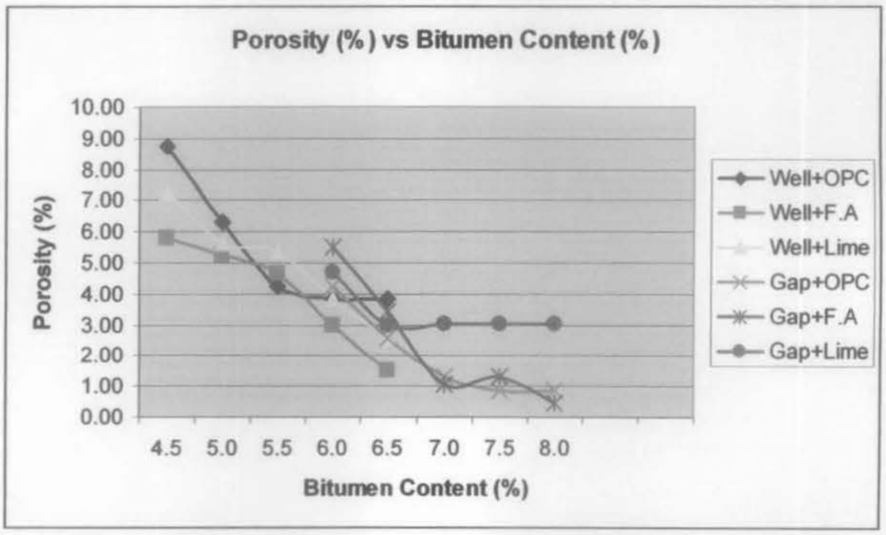

Figure 4.2 : Porosity vs. Bitumen Content

As the existence of high void rate in asphalt concrete may cause road surface stripping due to intruding water, road surface bleeding may occur if there is no sufficient void rate in asphalt concrete. Thus, the void rate is important because it can affect the durability of asphalt concrete pavement. In Figure 4.2, it can be seen that the void rate is decreased with increasing asphalt content for the six variations. Both the cases of well graded - lime and well graded – fly ash may slightly increase the void rate, which is good for preventing road surface bleeding and rutting.

4.3.3 Voids in Mineral Aggregate

As shown in Figure 4.3 is the VMA. versus asphalt content. The curves showed that the VMA is decreased with increasing asphalt content, after reaching a point, it becomes in proportion to the content of asphalt. The case of gap graded - OPC seems to have a higher VMA which may contain a sufficient amount of asphalt in the mixture to enhance the quality and durability of asphalt concrete pavement.

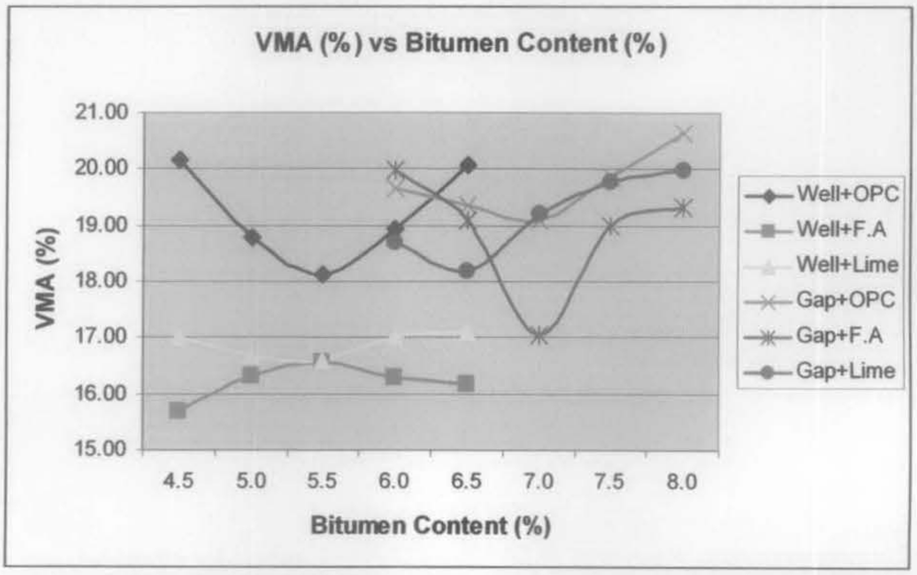

Figure 3.3 : Graph of VMA vs. Bitumen Content for Both Gradation

4.3.4 Flow

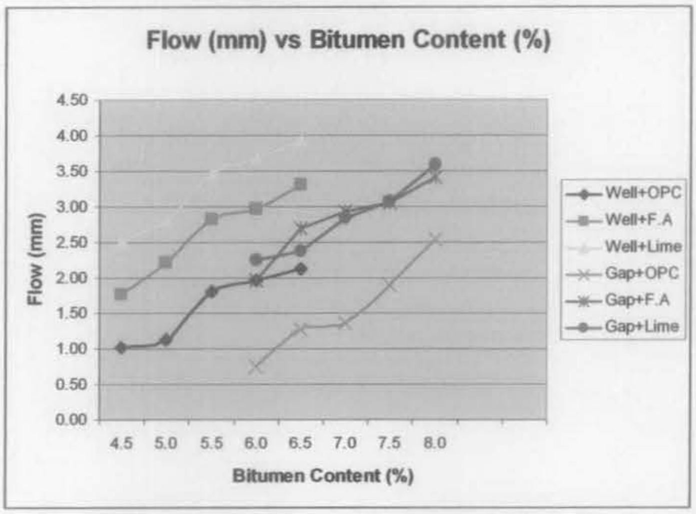

Figure 4.4 : Flow vs. Bitumen Content

The flow value denotes the deformation of asphalt concrete after damage. From the curves of Figure 4.4, it can be found that the flow value or the flexibility is in proportion to asphalt content for the six combinations, but the case of both gradation with lime has a tendency to fit in the code value more suitably. An adequate flexibility of asphalt concrete may prevent road surface cracking from repeated vehicle loadings.

4.3.5 Stability

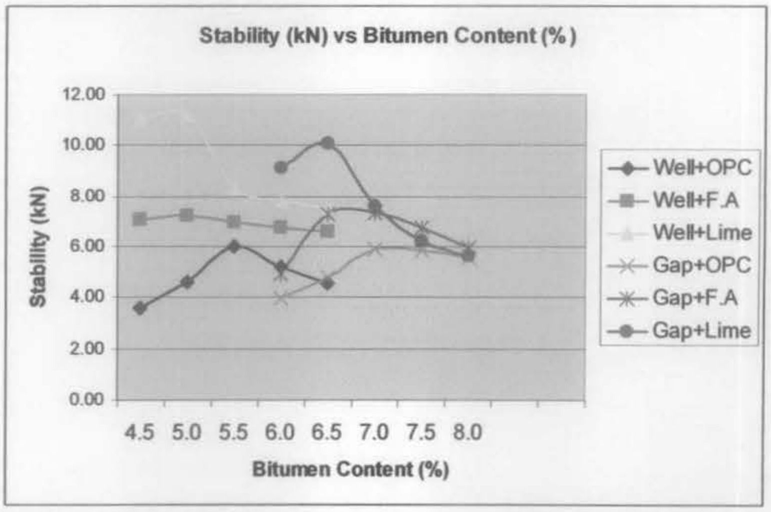

Figure 4.5 : Stability vs. Bitumen Content for Both Gradation

The stability value represents the ability to resist deformation due to vehicle loading. The curves in Figure 4.5 showed that combination of well graded and lime can produce a higher rigid road surface at 5.0% of bitumen content, while the gap graded and OPC produces a lowest stability value.

4.4 Wheel Tracking Test

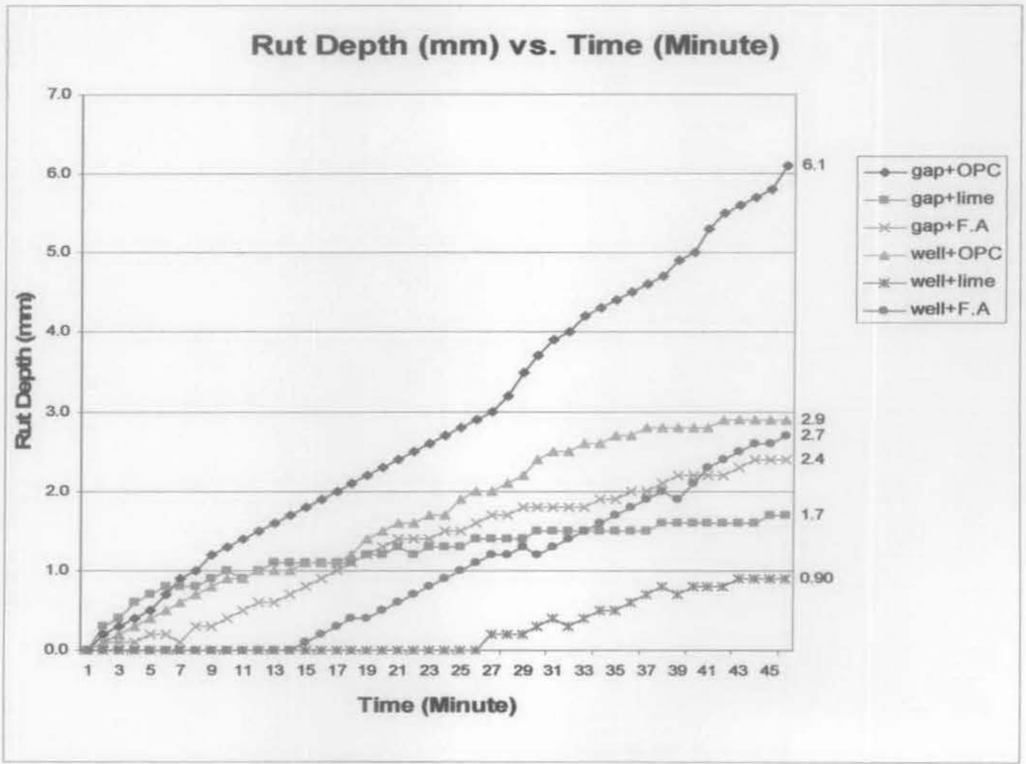

Figure 4.6 : Rutting Deformation at 40°C

From the above figure (Figure 4.6), it can be said that lime have the best performance in decreasing the rate of rutting. But, well gradation is better than gap gradation since it starts to rut at minute 26 compared to gap gradation which it starts to rut at minute 1. But, for case of fly ash, it works better with gap gradation rather than well gradation.

4.5 Creep Test

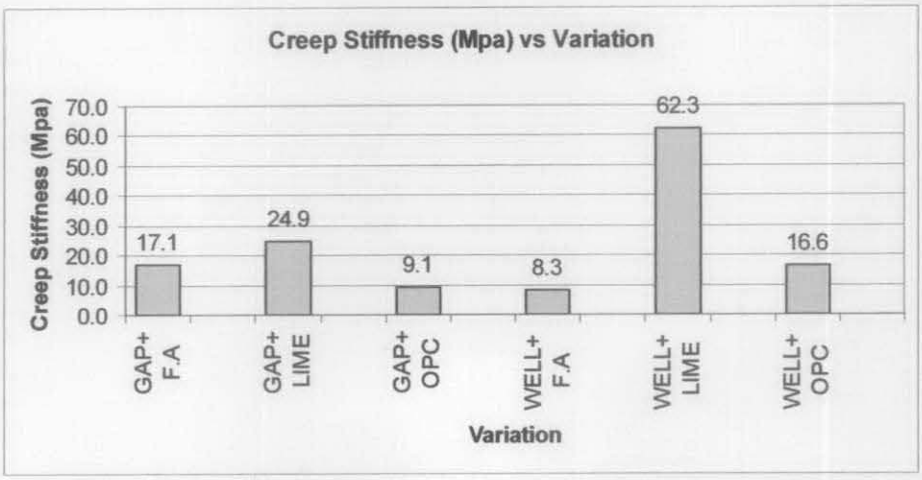

Figure 4.7 : Creep Stiffness vs. Different Variation at 40°C

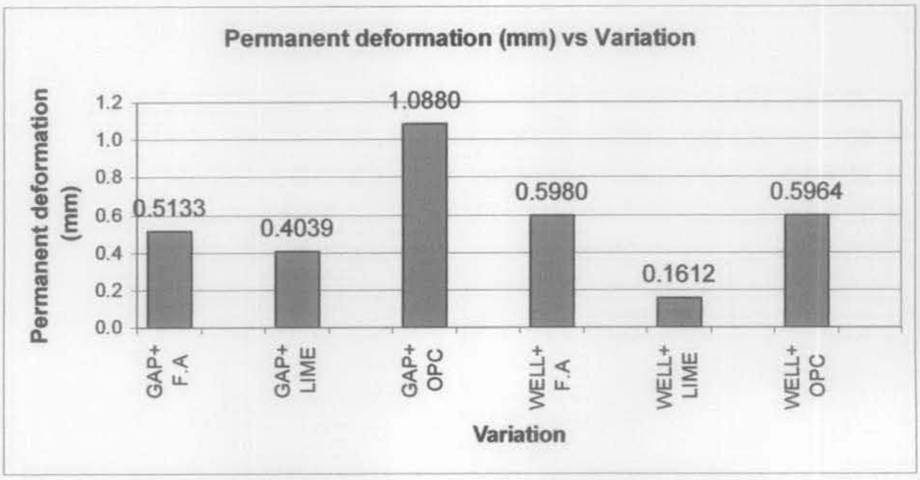

Figure 4.8 : Permanent Deformation vs. Different Variation at 40°C

The results (Refer to Figures 4.7 and 4.8) showed that hydrated lime had a mild effect on mixture stiffness. An ideal pavement should have a good viscoelastic property (higher stiffness) during a relatively high temperature to resist rutting during deformation. The level of deformation is the same with Wheel Tracking Test, where well-lime have the lowest deformation value and gap-OPC have the highest deformation value for the one hour test.

4.6 Indirect Tensile Fatigue Test

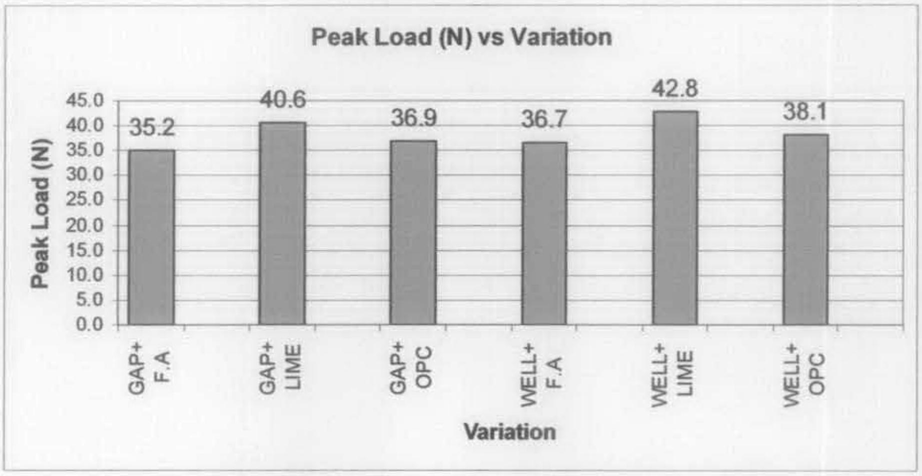

Figure 4.9 : Peak Load vs. Different Variation at 60°C

In Figure 4.9 it can be seen that well-lime also have the best performance on preventing pavement cracking compared to other five combinations. This test clearly demonstrated the fatigue superiority of hydrated lime in the HMA. The addition of hydrated lime to bitumen stiffens the bitumen because of the filler effect. Fly ash have the worst performance compared with two other fillers. This may be due to the smooth surface that fly ash particles have. Since it's particles roughness are less, it cannot bind well with other aggregate. Figure 4.10 also showed that well-lime is the best combination in resist deformation.

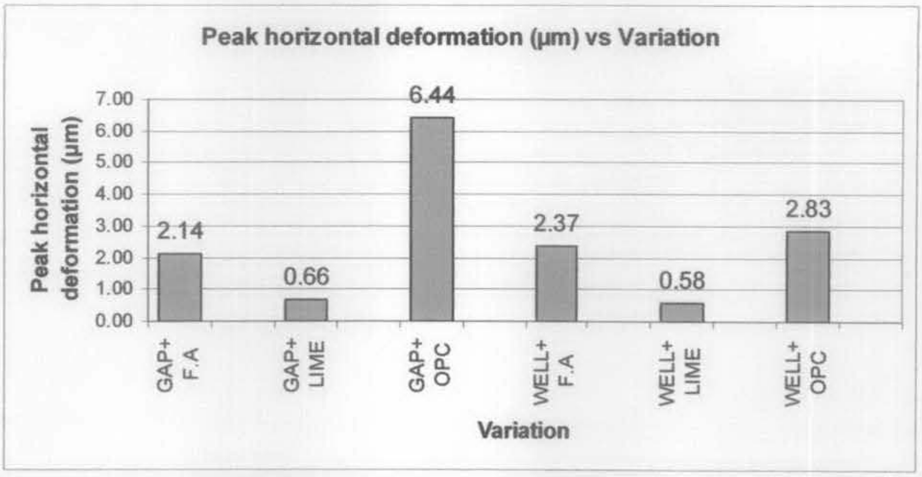

Figure 4.10 : Peak Horizontal Deformation vs. Different Variation at 60°C

4.7 Beam Fatigue Test

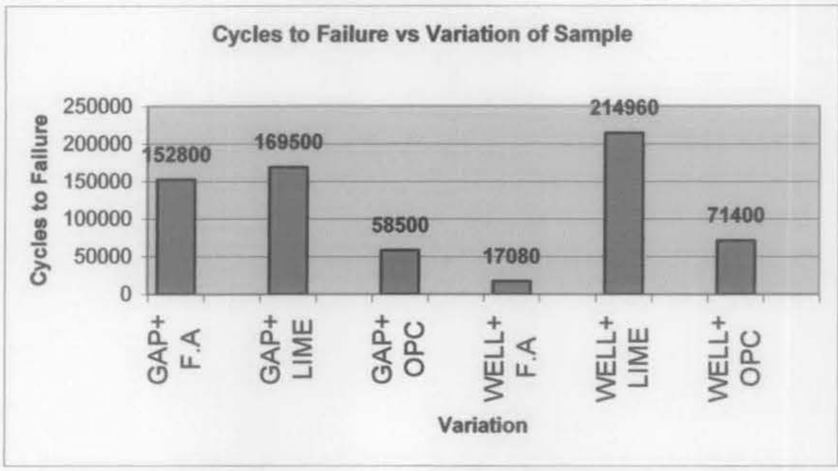

Figure 4.11 : Fatigue Life vs. Different Variation at 20°C

The results (Figures 4.11 and 4.12) showed that hydrated lime in well gradation had a mild effect on mixture stiffness but a significant effect on fatigue life. The stiffness of the bitumen is virtually comparable with the creep stiffness from the previous Creep Test. But the fatigue life is vastly improved where the difference between the longest fatigue life (well-lime) with the shortest fatigue life (well-PFA) is largely different. This study on cyclic tensile fatigue test conclude that addition of lime is the best way to increased the duration of fatigue life.

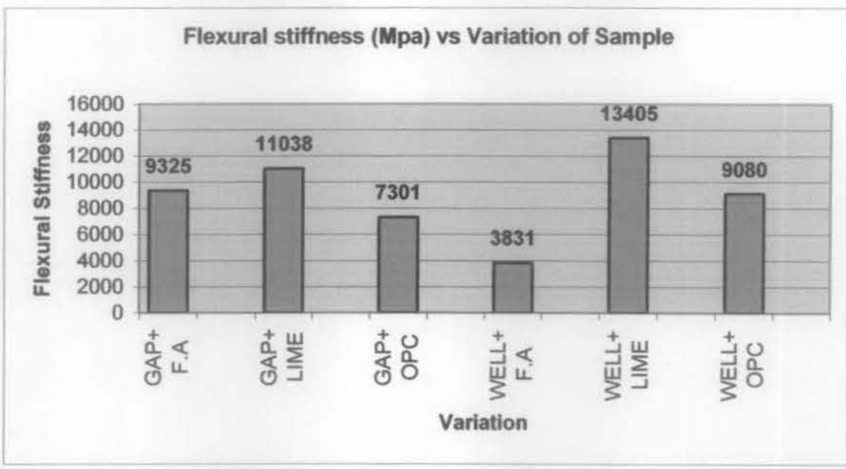

Figure 4.12 : Flexural Stiffness vs. Different Variation at 20°C

4.8 Penetration Test on Bitumen with Different Filler as Additive

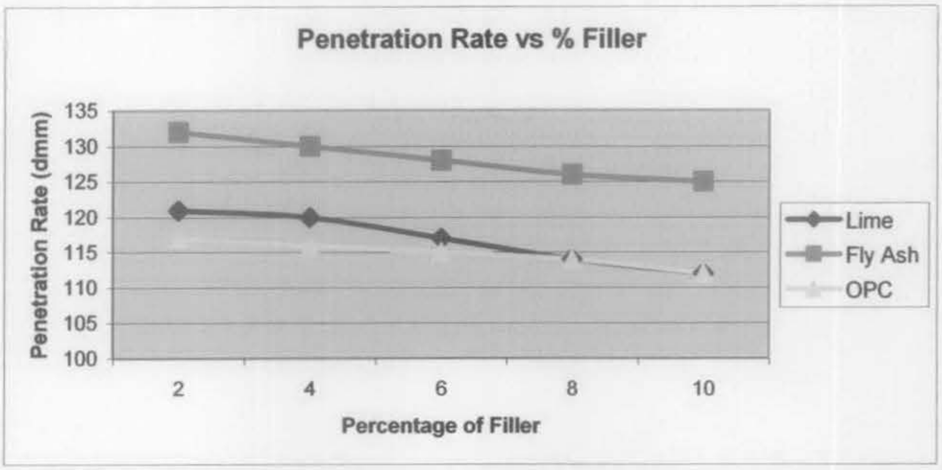

Figure 4.13 : Penetration Rate vs. Different Percentage of Different Filler as Additive

Figure 4.13 showed that by increasing the percentage of filler as additive in the bitumen, the penetration rate are decreasing for all types of filler used. Pulverised Fly Ash have the greatest penetration rate among the three fillers which means that PFA will soften the bitumen more than lime and OPC. From this additional test, it can be described why combination of fly ash and well graded with OBC 6.77% cannot work well since fly ash will make the bitumen softer.

From the above experimental results, it may conclude that the case of well graded with 8% lime is a better choice for using in asphalt concrete mixture. But why is lime relatively more effective than cement? By analyzing the fundamental physical properties of each additive as seen in Table 4.4, it can be found that the lime has the smallest specific gravity. That is, the relatively lighter unit weight, larger fineness and rougher grain surface of lime may fill in the void of asphalt mortar more densely. Therefore, it exhibits a better performance in several items of experimental results.

Lime chemically active rather than inert. It reacts with the bitumen, removing undesirable components at the same time that its tiny particles disperse throughout the mix, making the pavement more resistant to rutting and cracking.

The statistical methods and a long term on-site evaluation may be used to assess the true variation in effect. However in practice, all the fillers are cheap and can easily be used in resisting asphalt concrete stripping, the lime seems to perform slightly better at least in the present laboratory work results.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Six variations of different combination (filler and gradation) were analyzed to make comparisons. The experiment results have shown that different filler material and gradation have different performance on rutting and cracking. Combination of well graded and lime have the advantages of increasing the viscoelastic property and the stiffness and compactness to reduce negative impacts on the asphalt concrete road surface.

In particular, with 8% lime as filler in the well gradation, several positive data could be obtained including:

1. An adequate void rate,
2. An adequate flexibility (flow),
3. A higher stability value,
4. A lower rutting deformation rate,
5. A higher stiffness and,
6. A longer fatigue life.

Table 5.1 : Summary of Conclusion

Characteristic	Advantage	Factor
Adequate void rate	Good for preventing road surface bleeding and rutting.	• Relatively lighter unit weight, larger fineness and rougher grain surface of lime may fill in the void of asphalt mortar
Adequate flexibility (flow)	May prevent road surface cracking from repeated vehicle loadings.	

<table>
<tr><td>Higher stability value</td><td>Better resistance on deformation due to vehicle loading.</td><td rowspan="4">more densely.
• Chemically active rather than inert. It reacts with the bitumen, removing undesirable components at the same time that its tiny particles disperse throughout the mix.
• Portlandite as the main chemical composition helps in increasing the pozzolanic reaction to form hydrates possesing cementitious properties.</td></tr>
<tr><td>Lower rutting deformation rate</td><td>More economical since less maintenance work need to be done.</td></tr>
<tr><td>Higher stiffness</td><td>A good viscoelastic property (higher stiffness) during high temperature to resist rutting during deformation.</td></tr>
<tr><td>Longer fatigue life</td><td>More economical since longer service life can lessen the maintenance work.</td></tr>
</table>

These results might have proved that the combination of lime and well gradation could increase the abilities of antistripping and resist the rutting deformation and thus might increase the durability and usage life of the asphalt concrete road surface.

5.2 Recommendation

From the results that have been obtained throughout the research, it was observed that all the properties are connected with each other. It was obvious that different filler material have an effect towards the performance on rutting and cracking.

It is suggested that to further this study using different filler material especially waste material such as scrapped tire rubber (STR) and latex, coconut shell ash and coconut fiber, sugar mill residue ash, or oil palm shell ash.

It is also recommended to try different source of fine aggregate such as screen quarry fines and mining sand.

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APPENDIX A

Table A1 : Gradation Limit for Well Graded (JKR Specification Limit - AC20)

B.S Sieve Size		**% Passing by Weight**
37.5	mm	-
28.0	mm	100
20.0	mm	76-100
14.0	mm	64-89
10.0	mm	56-81
5.0	mm	46-71
3.35	mm	32-58
1.18	mm	20-42
425	µm	12-28
150	µm	6-16
75	µm	4-8

Table A2 : Gradation Limit for Gap Graded (BS Specification Limit)

B.S Sieve Size		% Passing by Weight
20.00	mm	100
14.00	mm	85-100
10.00	mm	60-90
6.30	mm	-
5.00	mm	-
2.36	mm	60-72
0.60	mm	45-72
0.30	mm	-
0.212	mm	15-50
0.125	mm	-
0.09	mm	-
0.075	mm	8-12
0.063	mm	-
0.045	mm	-

APPENDIX B

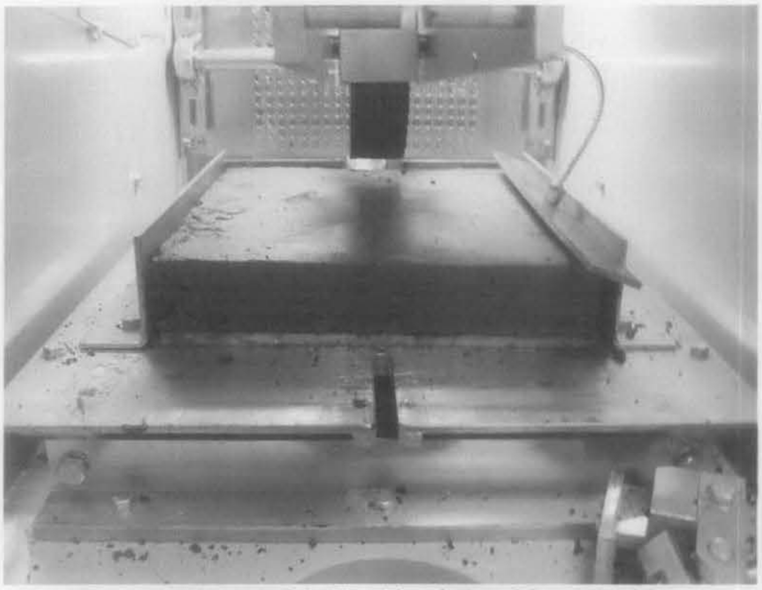

Figure B1 : WESSEX Wheel Tracking Machine

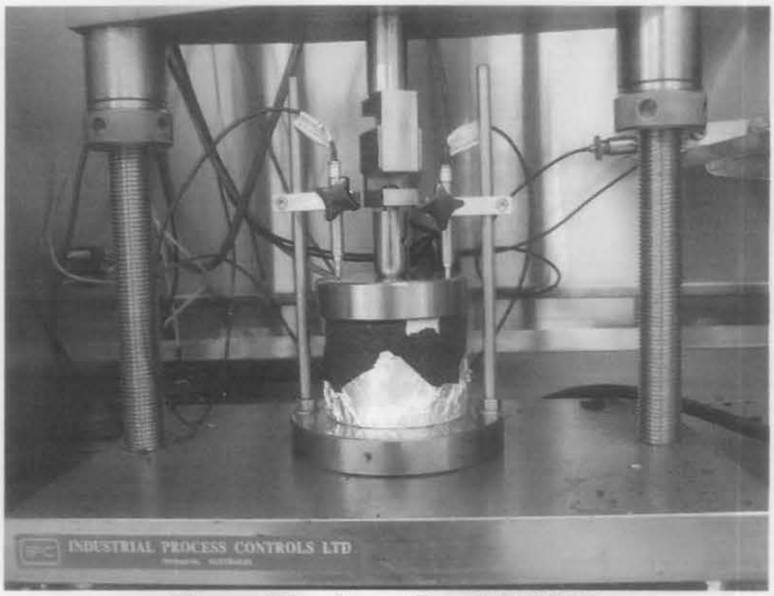

Figure B2 : Creep Test (MATTA)

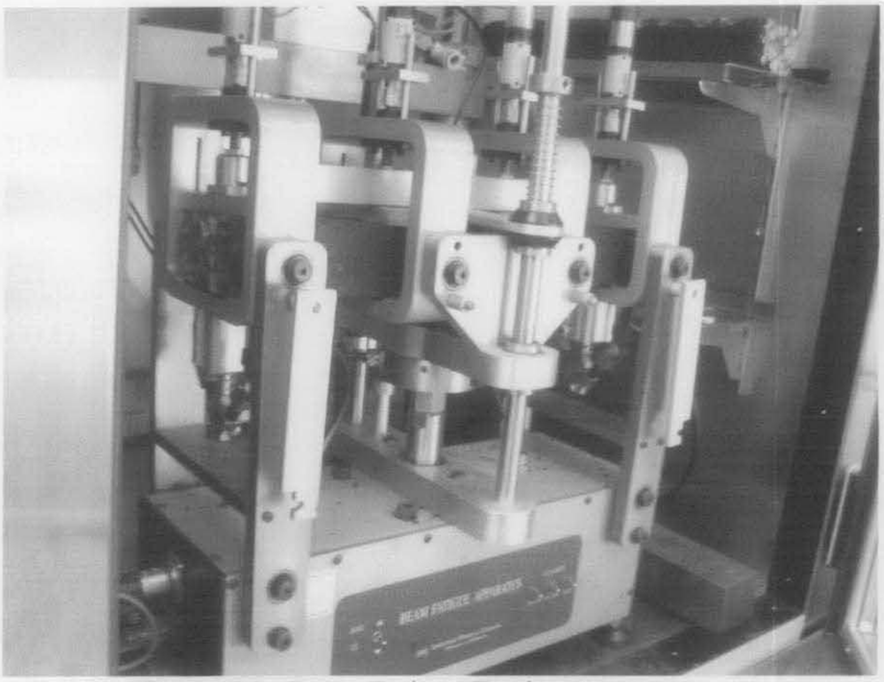

Figure B3 : Beam Fatigue Testing Apparatus

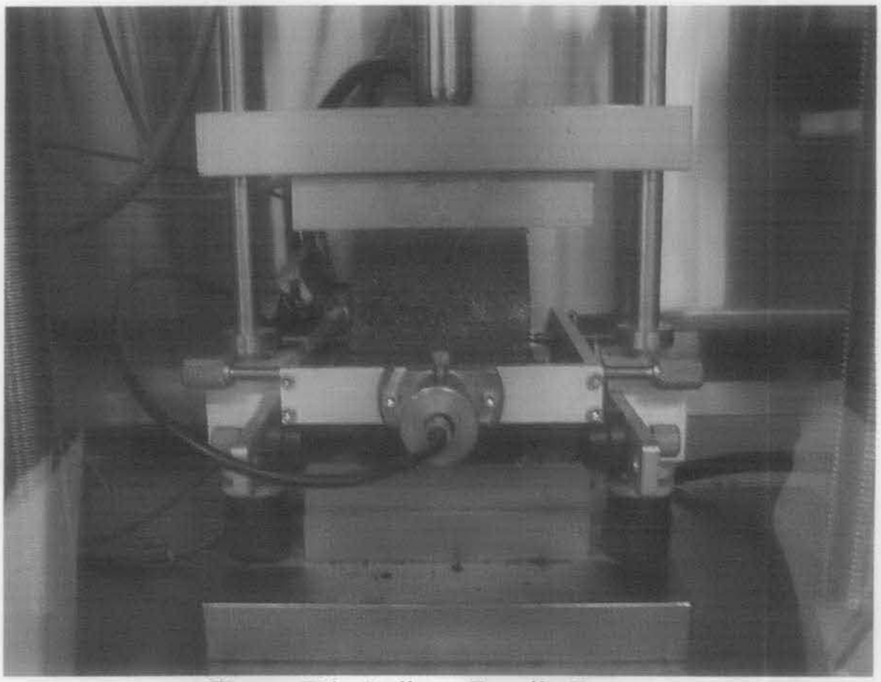

Figure B4 : Indirect Tensile Test

APPENDIX C

Table C1 : Result of Particle Density for Coarse Aggregate

			Test No. 1	Test No. 2
Mass of Saturated surface-dry sample in air	A	(g)	1075.0	1080.3
Mass of vessel containing sample and filled with water	B	(g)	2212.1	2224.2
Mass of vessel filled with water only	C	(g)	1562.1	1563.1
Mass of oven-dry sample in air	D	(g)	1065.6	1071.9

		Test No. 1	Test No. 2	Average
Bulk Specific Gravity (Gsb)	$\frac{D}{A-(B-C)}$	2.507	2.557	2.532
Bulk SSD Specific Gravity (Gsb SSD)	$\frac{A}{A-(B-C)}$	2.529	2.577	2.553
Apparent Specific Gravity (Gsa)	$\frac{D}{D-(B-C)}$	2.564	2.609	2.587
Water absorption (% of dry mass)	$\frac{100(A-D)}{D}$	0.882	0.783	0.833

Table C2 : Result for Aggregate Abrasion Value Test for Coarse Aggregate

		Test1
Mass of aggregate retained on No. 4 ASTM sieve, M_1	kg	5.0
Mass of material passing No. 12 ASTM sieve, M_2	kg	0.9
Los Angeles abrasion value $\frac{M_2}{M_1}$ x 100%	%	18

Table C3 : Result for Aggregate Impact Value Test for Coarse Aggregate

		1	2
Nett weight of the aggregate in the measure (A)	(g)	796.00	798.00
Weight of sample coarser than 2.36 mm (no.8) sieve. (B)	(g)	606.00	607.00
Weight of sample retained in the pan. (C)	(g)	190.00	191.00
Aggregate Impact Value (AIV)	(%)	23.87	23.93

Table C4 : Result of Particle Density for Fine Aggregate

			Test No. 1	Test No. 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	491

		Test No. 1	Test No. 2	Average
Bulk Specific Gravity (Gsb)	$\frac{D}{A-(B-C)}$	2.552	2.544	2.548
Bulk SSD Specific Gravity (Gsb SSD)	$\frac{A}{A-(B-C)}$	2.562	2.560	2.561
Apparent Specific Gravity (Gsa)	$\frac{D}{D-(B-C)}$	2.578	2.584	2.581
Water absorption (% of dry mass)	$\frac{100(A-D)}{D}$	0.404	0.611	0.508

Table C5 : Result of Specific Gravity Test for Bitumen

		Test No.	
		1	2
Mass of pycnometer (plus stopper) (A)	(g)	19.0	19.4
Mass of pycnometer filled with water (B)	(g)	45.3	44.8
Mass of pycnometer partially filled with asphalt (C)	(g)	31.0	31.5
Mass of pycnometer plus asphalt plus water (D)	(g)	45.6	45.1
Relative density = (C-A)/[(B-A)-(D-C)]		1.026	1.025
Average relative density		1.026	

Table C6 : Result of Softening Point Test

Trial	Ball 1	Ball 2	Mean
1	54.4	52.6	53.5
2	48.0	48.6	48.3

Table C7 : Result of Ductility Test

Mould No. 1	Mould No. 2	Mould No. 3	Mean
112.3 cm	103.0 cm	121.5 cm	116.9 cm

Table C8 : Result Standard Penetration Test

Standard Penetration Test				
Temperature : *25°C*		Load : *100 g*		Time : *5 seconds*
Sample No.	Determination 1	Determination 2	Determination 3	Mean
A	88	88	85	87
B	86	86	84	85

Table C9 : Result of Wheel Tracking Test for Gap Graded

Gap+F.A		Gap+lime		Gap+OPC	
Minutes	Depth	Minutes	Depth	Minutes	Depth
0	0.00	0	0.00	0	0.00
1	0.10	1	0.30	1	0.20
2	0.10	2	0.40	2	0.30
3	0.10	3	0.60	3	0.40
4	0.20	4	0.70	4	0.50
5	0.20	5	0.80	5	0.70
6	0.10	6	0.80	6	0.90
7	0.30	7	0.80	7	1.00
8	0.30	8	0.90	8	1.20
9	0.40	9	1.00	9	1.30
10	0.50	10	0.90	10	1.40
11	0.60	11	1.00	11	1.50
12	0.60	12	1.10	12	1.60
13	0.70	13	1.10	13	1.70
14	0.80	14	1.10	14	1.80
15	0.90	15	1.10	15	1.90
16	1.00	16	1.10	16	2.00
17	1.10	17	1.10	17	2.10
18	1.20	18	1.20	18	2.20
19	1.30	19	1.20	19	2.30
20	1.40	20	1.30	20	2.40
21	1.40	21	1.20	21	2.50
22	1.40	22	1.30	22	2.60
23	1.50	23	1.30	23	2.70
24	1.50	24	1.30	24	2.80
25	1.60	25	1.40	25	2.90
26	1.70	26	1.40	26	3.00
27	1.70	27	1.40	27	3.20
28	1.80	28	1.40	28	3.50
29	1.80	29	1.50	29	3.70
30	1.80	30	1.50	30	3.90
31	1.80	31	1.50	31	4.00
32	1.80	32	1.50	32	4.20
33	1.90	33	1.50	33	4.30
34	1.90	34	1.50	34	4.40
35	2.00	35	1.50	35	4.50
36	2.00	36	1.50	36	4.60
37	2.10	37	1.60	37	4.70
38	2.20	38	1.60	38	4.90
39	2.20	39	1.60	39	5.00
40	2.20	40	1.60	40	5.30
41	2.20	41	1.60	41	5.50
42	2.30	42	1.60	42	5.60
43	2.40	43	1.60	43	5.70
44	2.40	44	1.70	44	5.80
45	2.40	45	1.70	45	6.10

Table C10 : Result of Wheel Tracking Test for Well Graded

Well+F.A		Well+lime		Well+OPC	
Minutes	Depth	Minutes	Depth	Minutes	Depth
0	0.00	0	0.00	0	0.0
1	0.00	1	0.00	1	0.1
2	0.00	2	0.00	2	0.2
3	0.00	3	0.00	3	0.3
4	0.00	4	0.00	4	0.4
5	0.00	5	0.00	5	0.5
6	0.00	6	0.00	6	0.6
7	0.00	7	0.00	7	0.7
8	0.00	8	0.00	8	0.8
9	0.00	9	0.00	9	0.9
10	0.00	10	0.00	10	0.9
11	0.00	11	0.00	11	1.0
12	0.00	12	0.00	12	1.0
13	0.00	13	0.00	13	1.0
14	0.1	14	0.00	14	1.1
15	0.2	15	0.00	15	1.1
16	0.3	16	0.00	16	1.1
17	0.4	17	0.00	17	1.2
18	0.40	18	0.00	18	1.4
19	0.50	19	0.00	19	1.5
20	0.60	20	0.00	20	1.6
21	0.70	21	0.00	21	1.6
22	0.80	22	0.00	22	1.7
23	0.90	23	0.00	23	1.7
24	1.00	24	0.00	24	1.9
25	1.10	25	0.00	25	2.0
26	1.20	26	0.20	26	2.0
27	1.20	27	0.20	27	2.1
28	1.30	28	0.20	28	2.2
29	1.20	29	0.30	29	2.4
30	1.30	30	0.40	30	2.5
31	1.40	31	0.30	31	2.5
32	1.50	32	0.40	32	2.6
33	1.60	33	0.50	33	2.6
34	1.70	34	0.50	34	2.7
35	1.80	35	0.60	35	2.7
36	1.90	36	0.70	36	2.8
37	2.00	37	0.80	37	2.8
38	1.90	38	0.70	38	2.8
39	2.10	39	0.80	39	2.8
40	2.30	40	0.80	40	2.8
41	2.40	41	0.80	41	2.9
42	2.50	42	0.90	42	2.9
43	2.60	43	0.90	43	2.9
44	2.60	44	0.90	44	2.9
45	2.70	45	0.90	45	2.9

Table C11 : Result of Creep Test

CREEP TEST					
		A	B	C	Average
GAP+ F.A	Permanent deformation (mm)	0.5152	0.5113	0.5678	0.5133
	Creep stiffness (Mpa)	14.8	19.3	5.4	17.1
GAP+ LIME	Permanent deformation (mm)	1.6746	0.3926	0.4151	0.4039
	Creep stiffness (Mpa)	60.0	25.6	24.1	24.9
GAP+ OPC	Permanent deformation (mm)	1.0879	1.0869	1.0891	1.0880
	Creep stiffness (Mpa)	9.6	8.7	9.0	9.1
WELL+ F.A	Permanent deformation (mm)	0.6746	0.5214	1.8651	0.5980
	Creep stiffness (Mpa)	9.9	6.6	4.4	8.3
WELL+ LIME	Permanent deformation (mm)	0.3639	0.1538	0.1685	0.1612
	Creep stiffness (Mpa)	27.7	65.2	59.3	62.3
WELL+ OPC	Permanent deformation (mm)	0.5969	0.5961	0.5966	0.5964
	Creep stiffness (Mpa)	17.4	16.8	16.3	16.6

Table C12 : Result of Indirect Tensile Fatigue Test

IDT TEST					
		A	B	C	Average
GAP+ F.A	Peak horizontal deformation (μm)	2.17	2.11	3.84	2.14
	Peak load (N)	35.8	34.6	34.6	35.2
GAP+ LIME	Peak horizontal deformation (μm)	1.54	0.55	0.77	0.66
	Peak load (N)	148.5	38.3	42.8	40.6
GAP+ OPC	Peak horizontal deformation (μm)	6.7	6.17	5.9	6.44
	Peak load (N)	36.9	36.9	35.8	36.9
WELL+ F.A	Peak horizontal deformation (μm)	1.73	3.01	4.30	2.37
	Peak load (N)	38.1	35.2	39.3	36.7
WELL+ LIME	Peak horizontal deformation (μm)	0.55	0.68	0.60	0.58
	Peak load (N)	42.0	35.8	43.5	42.8
WELL+ OPC	Peak horizontal deformation (μm)	2.41	3.01	2.72	2.57
	Peak load (N)	38.1	36.9	38.2	38.2

Table C13 : Result of Beam Fatigue Test

Sample	Cycles count	Flexural stiffness (Mpa)
GAP+ F.A	152800	9325
GAP+ LIME	169500	11038
GAP+ OPC	58500	7301
WELL+ F.A	17080	3831
WELL+ LIME	214960	13405
WELL+ OPC	71400	9080

Table C14 : Marshall Analysis (Gap Graded - OPC)

Bitumen Grade: 80/100 Specific Gravity of Bitumen: 1.03 Specific Gravity of Agg: 2.60
Aggregate Gradation: Gap Graded Course Agg: 35 %, 420 g Fine Agg: 55 %, 660 g Filler: 10 %, 120 g

Binder Content (%)	Sample No.	Height (mm)	Mass of Specimen		Volume (cm^3)	Specific Gravity		Air Voids (%)		Flow (mm)	Stability (kN)		
			In Air (g)	In Water (g)		Bulk	Theory	Total Mix	VMA		Measured	C.F.	Corrected
6.0	1	70.70	1255.5	698.5	557.0	2.25	2.35	4.26	19.64	0.72	4.75	0.89	4.23
	2	71.37	1245.0	692.5	552.5					0.78	4.23	0.86	3.64
6.5	1	71.09	1258.0	704.0	554.0	2.27	2.33	2.58	19.36	0.90	5.69	0.86	4.89
	2	71.49	1222.0	683.5	538.5					1.63	5.45	0.86	4.69
7.0	1	71.70	1262.5	713.0	549.5	2.29	2.32	1.30	19.08	1.51	6.92	0.83	5.74
	2	71.51	1273.0	719.0	554.0					1.21	7.02	0.86	6.04
7.5	1	70.48	1276.5	722.5	554.0	2.28	2.30	0.87	19.87	1.75	6.72	0.86	5.78
	2	71.06	1272.0	718.0	554.0					2.05	6.85	0.86	5.89
8.0	1	70.36	1257.5	709.5	545.0	2.27	2.29	0.87	20.65	2.45	6.56	0.86	5.64
	2	71.53	1259.5	710.5	549.0					2.60	5.77	0.96	5.54

Table C15 : Marshall Analysis (Well Graded - OPC)

Bitumen Grade: 80/100 Specific Gravity of Bitumen: 1.03 Specific Gravity of Agg: 2.60
Aggregate Gradation: Well Graded Course Agg: 42 %, 504 g Fine Agg: 50 %, 600 g Filler: 8 %, 96 g

Binder Content (%)	Sample No.	Height (mm)	Mass of Specimen		Volume (cm^3)	Specific Gravity		Air Voids (%)		Flow (mm)	Stability (kN)		
			In Air (g)	In Water (g)		Bulk	Theory	Total Mix	VMA		Measured	C.F.	Corrected
4.5%	1	69.64	1210.5	654.5	556.0	2.19	2.40	8.75	20.17	0.93	3.95	0.89	3.52
	2	71.03	1215.5	655.0	560.5					1.09	4.23	0.86	3.64
5.0%	1	70.15	1239.5	678.0	561.5	2.24	2.38	6.30	18.78	1.15	5.15	0.86	4.43
	2	69.07	1221.0	669.0	552.0					1.08	5.43	0.89	4.83
5.5%	1	71.18	1248.0	684.0	564.0	2.27	2.37	4.22	18.12	1 .72	6.51	0.86	5.60
	2	70.12	1233.0	686.0	547.0					1.90	7.24	0.89	6.44
6.0%	1	71.10	1268.0	694.0	574.0	2.26	2.35	3.83	18.92	1.95	6.03	0.83	5.00
	2	69.07	1250.5	687.0	563.5					2.01	6.22	0.86	5.35
6.5%	1	70.81	1268.5	699.5	569.0	2.24	2.33	3.86	20.06	2.05	5.21	0.86	4.48
	2	70.36	1253.0	680.0	573.0					2.18	5.40	0.86	4.64

Table C16 : Marshall Analysis (Gap Graded – Fly Ash)

Bitumen Grade		SG Agg = 2.58				SG Bit = 1.026							
Dry Mix		Coarse Aggregate = 35%				Fine Aggregate = 55%				Filler = 10%			
Sample no.	Binder Content By Mass of Mix (%)	Height (mm)	Mass of Specimen		Volume (cm³)	Specific Gravity of mix		Air Voids (%)		Flow (mm)	Stability (kN)		
			In Air (g)	In Water (g)		Bulk	Max	Porosity	VMA		Measured	C.F.	Corrected
	A	B	C	D	E	F	G	H	I	J	K	L	M
A	6.0	70.19	1235.5	678.5	557.0	2.22	2.35	5.53	19.74	1.44	4.91	0.89	4.37
B		71.73	1250.0	682.0	568.0	2.20		6.38	20.46	2.09	6.00	0.86	5.16
C		70.08	1252.0	689.0	563.0	2.22		5.53	19.74	1.84	6.05	0.86	5.20
						2.21		5.53	19.98	1.97	5.65		4.91
A	6.5	69.92	1254.0	691.0	563.0	2.23	2.33	4.29	19.81	2.31	6.95	0.86	5.98
B		69.39	1267.5	709.5	558.0	2.27		2.58	18.37	2.78	7.66	0.89	6.82
C		65.99	1213.5	689.0	524.5	2.31		0.86	16.93	2.62	8.06	0.96	7.74
						2.27		3.44	19.09	2.70	7.56		7.28
A	7.0	68.86	1269.5	719.0	550.5	2.31	2.32	0.43	17.37	2.99	8.21	0.89	7.31
B		67.69	1255.0	710.0	545.0	2.30		0.86	17.73	2.85	8.76	0.89	7.80
C		68.32	1248.5	703.5	545.0	2.29		1.29	18.09	2.96	8.24	0.89	7.33
						2.30		1.08	17.73	2.93	8.40		7.32
A	7.5	69.33	1265.5	712.5	553.0	2.29	2.30	0.43	18.53	3.02	7.61	0.89	6.77
B		69.53	1265.0	707.0	558.0	2.27		1.30	19.24	3.22	7.59	0.89	6.76
C		69.48	1263.0	707.0	556.0	2.27		1.30	19.24	3.08	7.36	0.89	6.55
						2.28		1.30	19.00	3.05	7.52		6.76
A	8.0	68.99	1253.0	700.5	552.5	2.27	2.29	0.87	19.68	3.43	6.55	0.89	5.83
B		69.78	1254.0	704.0	550.0	2.28		0.44	19.32	3.39	6.67	0.89	5.94
C		69.52	1270.0	712.0	558.0	2.28		0.44	19.32	3.65	6.75	0.89	6.01
						2.27		0.44	19.44	3.41	6.66		5.92

Table C17 : Marshall Analysis (Well Graded – Fly Ash)

Bitumen Grade		SG Agg = 2.58				SG Bit = 1.03							
Dry Mix		Coarse Aggregate = 42%				Fine Aggregate = 50%				Filler = 8%			
Sample no.	Binder Content By Mass of Mix (%)	Height (mm)	Mass of Specimen		Volume (cm³)	Specific Gravity of mix		Air Voids (%)			Stability (kN)		
			In Air (g)	In Water (g)		Bulk	Max	Porosity	VMA	Flow (mm)	Measured	C.F.	Corrected
	A	B	C	D	E	F	G	H	I	J	K	L	M
A	4.5	69.88	1255.0	699.0	556.0	2.26		5.83	15.69	1.85	7.81	0.89	6.95
B		67.71	1214.0	675.0	539.0	2.25	2.40	6.25	16.06	1.74	8.92	0.93	8.30
C		68.48	1226.0	684.0	542.0	2.26		5.83	15.69	1.73	7.70	0.93	7.16
						2.26		5.83	15.69	1.77	8.14		7.06
A	5.0	68.37	1236.0	691.5	544.5	2.27		4.62	15.76	2.13	7.92	0.93	7.37
B		68.73	1229.5	683.5	546.0	2.25	2.38	5.46	16.50	1.67	7.73	0.93	7.19
C		68.66	1239.0	690.5	548.5	2.26		5.04	16.13	2.28	7.98	0.89	7.10
						2.26		5.25	16.32	2.21	7.88		7.22
A	5.5	69.11	1246.5	695.5	551.0	2.26		4.64	16.57	2.74	7.10	0.93	6.60
B		68.22	1227.0	685.0	542.0	2.26	2.37	4.64	16.57	2.87	7.91	0.93	7.36
C		67.78	1226.0	682.5	543.5	2.26		4.64	16.57	2.89	7.25	0.93	6.74
						2.26		4.64	16.57	2.83	7.42		6.98
A	6.0	67.87	1235.0	693.5	541.5	2.28		2.98	16.28	2.96	7.34	0.89	6.53
B		68.54	1250.0	701.5	548.5	2.28	2.35	2.98	16.28	2.99	7.48	0.93	6.96
C		67.71	1243.0	702.0	541.0	2.30		2.13	15.55	2.93	7.89	0.93	7.34
						2.29		2.98	16.28	2.96	7.57		6.74
A	6.5	67.86	1246.0	702.5	543.5	2.29		1.72	16.36	3.39	7.18	0.93	6.68
B		67.09	1241.0	704.5	536.5	2.31	2.33	0.86	15.63	3.33	7.21	0.89	6.42
C		68.21	1254.5	708.5	546.0	2.30		1.29	16.00	3.20	7.11	0.93	6.61
						2.30		1.51	16.18	3.31	7.17		6.57

Table C18 : Marshall Analysis (Gap Graded – Lime)

Bitumen Grade		SG Agg = 2.57				SG Bit = 1.03							
Dry Mix		Coarse Aggregate = 35%				Fine Aggregate = 55%				Filler = 10%			
Sample no.	Binder Content By Mass of Mix (%)	Height (mm)	Mass of Specimen		Volume (cm³)	Specific Gravity of mix		Air Voids (%)		Flow (mm)	Stability (kN)		
			In Air (g)	In Water (g)		Bulk	Max	Porosity	VMA		Measured	C.F.	Corrected
	A	B	C	D	E	F	G	H	I	J	K	L	M
A	6.0	71.14	1264.5	704.0	560.5	2.26		4.21	18.34	2.25	9.75	0.86	8.39
B		68.64	1248.0	690.5	557.5	2.24	2.35	4.68	18.70	2.20	9.60	0.93	8.93
C		68.64	1250.0	692.0	558.0	2.24		4.68	18.70	2.29	10.02	0.93	9.32
						2.24		4.68	18.70	2.25	9.79		9.12
A	6.5	68.60	1251.0	702.5	548.5	2.28		2.15	17.69	2.39	10.89	0.93	10.13
B		60.38	1253.0	698.5	554.5	2.26	2.33	3.00	18.41	2.40	11.11	1.14	12.67
C		69.44	1259.0	702.0	557.0	2.26		3.00	18.41	2.32	11.28	0.89	10.04
						2.27		3.00	18.17	2.37	11.09		10.08
A	7.0	69.01	1238.5	685.5	553.0	2.24		3.45	19.57	2.85	8.61	0.89	7.66
B		69.79	1265.5	703.0	562.5	2.25	2.32	3.02	19.21	2.79	8.50	0.89	7.57
C		68.87	1265.0	703.0	562.0	2.25		3.02	19.21	2.88	9.03	0.89	8.04
						2.25		3.02	19.21	2.84	8.71		7.61
A	7.5	69.30	1253.0	691.0	562.0	2.23		3.04	19.76	3.03	7.03	0.89	6.26
B		71.92	1290.5	712.0	578.5	2.23	2.30	3.04	19.76	3.12	6.99	0.83	5.80
C		70.17	1254.5	691.5	563.0	2.23		3.04	19.76	3.07	7.00	0.89	6.23
						2.23		3.04	19.76	3.07	7.01		6.24
A	8.0	71.79	1291.5	706.5	585.0	2.21		3.49	19.79	3.55	6.39	0.86	5.50
B		69.29	1258.0	694.0	564.0	2.23	2.29	2.62	20.36	3.59	6.46	0.89	5.75
C		69.43	1254.0	686.0	568.0	2.21		3.49	19.79	3.62	6.42	0.89	5.71
						2.22		3.20	19.98	3.59	6.42		5.65

Table C19 : Marshall Analysis (Well Graded – Lime)

Bitumen Grade		SG Agg = 2.57				SG Bit = 1.03							
Dry Mix		Coarse Aggregate = 42 %				Fine Aggregate = 50 %				Filler = 8 %			
Sample no.	Binder Content By Mass of Mix (%)	Height (mm)	Mass of Specimen		Volume (cm³)	Specific Gravity of mix		Air Voids (%)			Stability (kN)		
			In Air (g)	In Water (g)		Bulk	Max	Porosity	VMA	Flow (mm)	Measured	C.F.	Corrected
	A	B	C	D	E	F	G	H	I	J	K	L	M
A	4.5	70.55	1251.0	689.5	561.5	2.23		7.08	16.81	2.49	13.10	0.86	11.27
B		69.70	1249.5	696.5	553.0	2.26	2.40	5.83	15.69	2.50	14.67	0.89	13.06
C		70.39	1244.5	685.0	559.5	2.22		7.50	17.18	2.56	12.51	0.86	10.76
						2.23		7.29	17.00	2.52	13.43		11.01
A	5.0	68.16	1205.5	655.5	550.0	2.19		7.98	18.73	2.88	12.51	0.89	11.13
B		69.77	1253.5	697.0	556.5	2.25	2.38	5.46	16.50	2.72	12.67	0.89	11.28
C		69.84	1229.0	681.0	548.0	2.24		5.88	16.88	3.10	12.48	0.89	11.11
						2.25		5.67	16.69	2.80	12.55		11.17
A	5.5	68.64	1246.5	698.5	548.0	2.27		4.22	16.21	3.43	9.32	0.89	8.29
B		67.70	1210.0	672.0	538.0	2.25	2.37	5.06	16.94	3.50	9.47	0.93	8.81
C		69.93	1238.0	682.5	555.5	2.23		5.61	17.68	3.47	9.41	0.89	8.37
						2.26		5.33	16.58	3.47	9.40		8.33
A	6.0	68.59	1252.0	702.5	549.5	2.28		2.98	16.34	3.61	8.80	0.89	7.83
B		69.90	1263.5	704.5	559.0	2.26	2.35	3.82	17.02	3.75	8.70	0.89	7.74
C		68.35	1235.0	688.0	547.0	2.26		3.82	17.02	3.30	8.79	0.89	7.82
						2.27		3.82	17.02	3.68	8.76		7.80
A	6.5	69.27	1251.5	701.0	550.5	2.27		2.58	17.09	3.90	8.37	0.89	7.45
B		68.38	1243.0	696.0	547.0	2.27	2.33	2.58	17.09	4.02	8.49	0.89	7.56
C		69.92	1275.5	716.0	559.5	2.28		2.15	16.73	3.84	8.70	0.86	7.48
						2.28		2.58	17.09	3.92	8.52		7.50

Table C20 : Penetration Test on Bitumen with Different Type of Filler and with Different Percentage

	Percentage of Filler (%)				
	2	4	6	8	10
	Penetration Rate (dmm)				
Lime	121	120	117	114	112
PFA	132	130	128	126	125
OPC	117	116	115	114	112

APPENDIX D

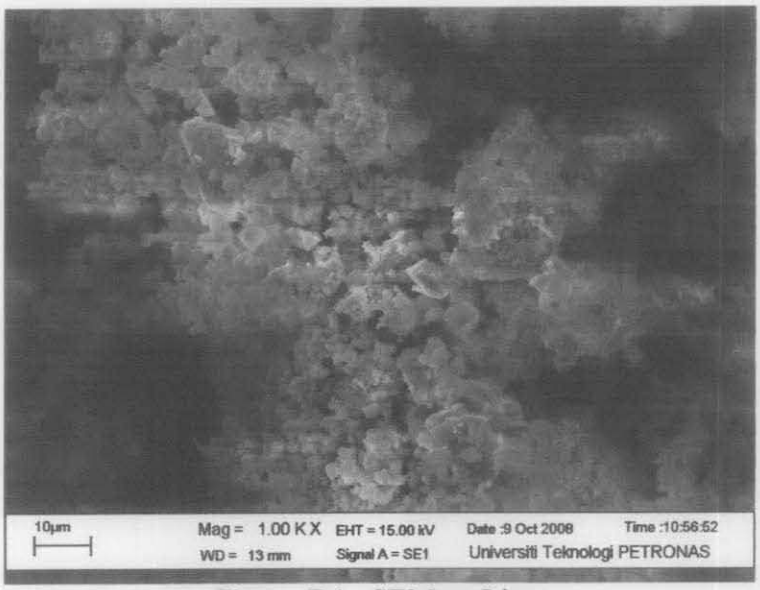

Figure D1 : SEM on Lime

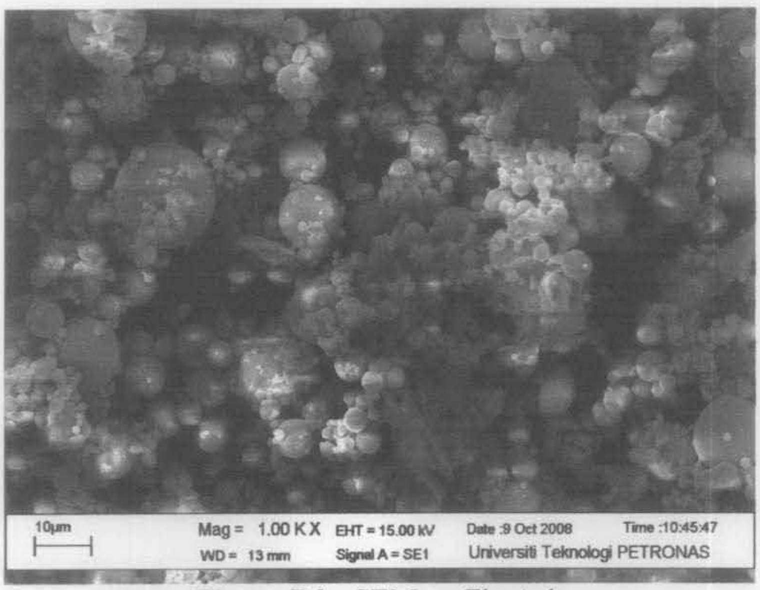

Figure D2 : SEM on Fly Ash

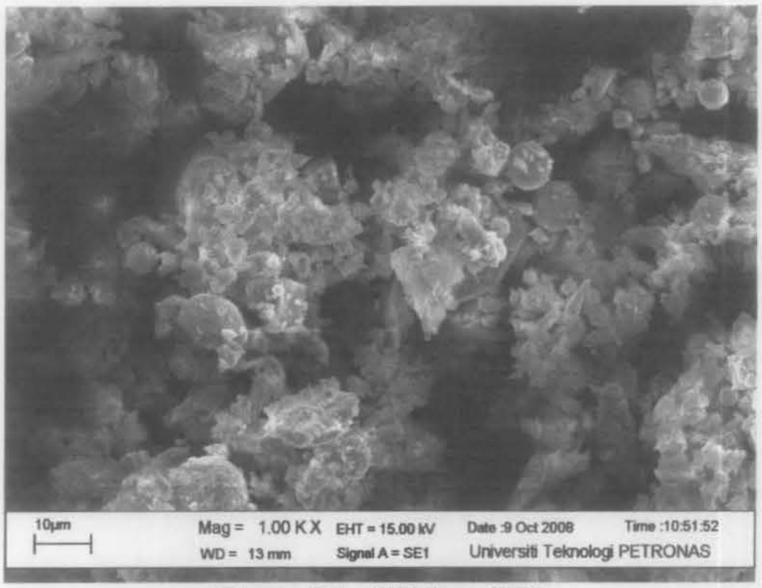

Figure D3 : SEM on OPC

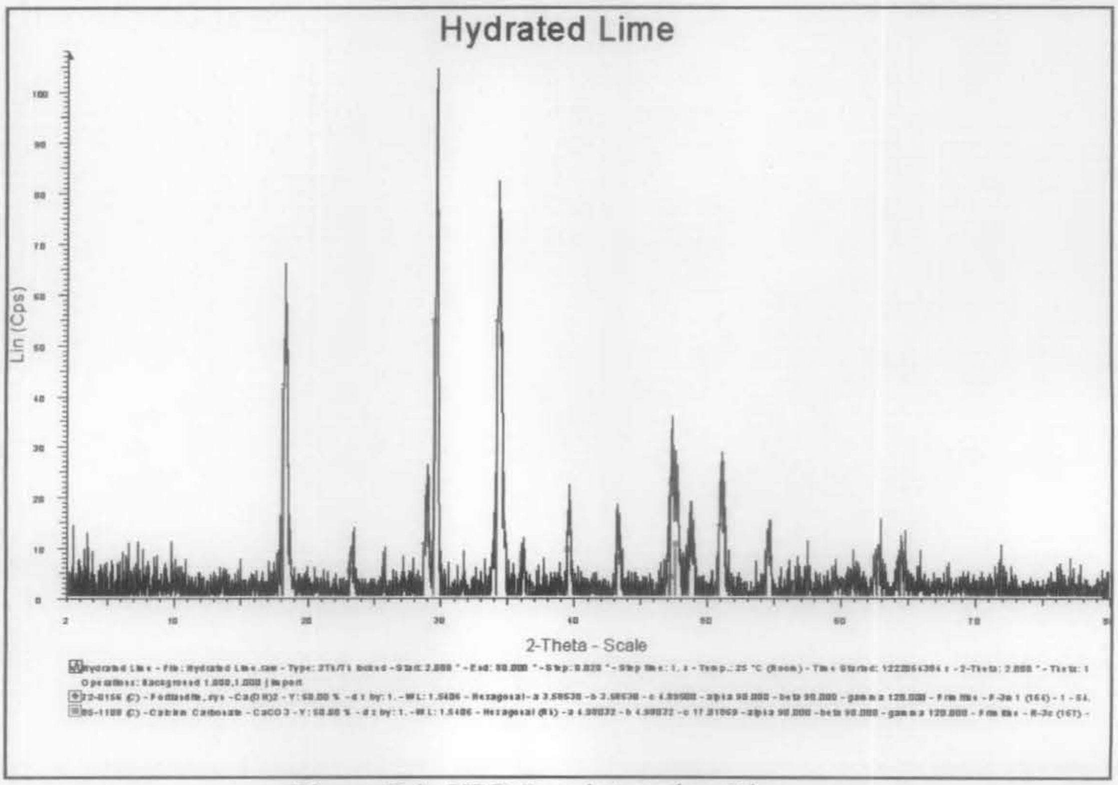

Figure D4 : XRD Result tested on Lime

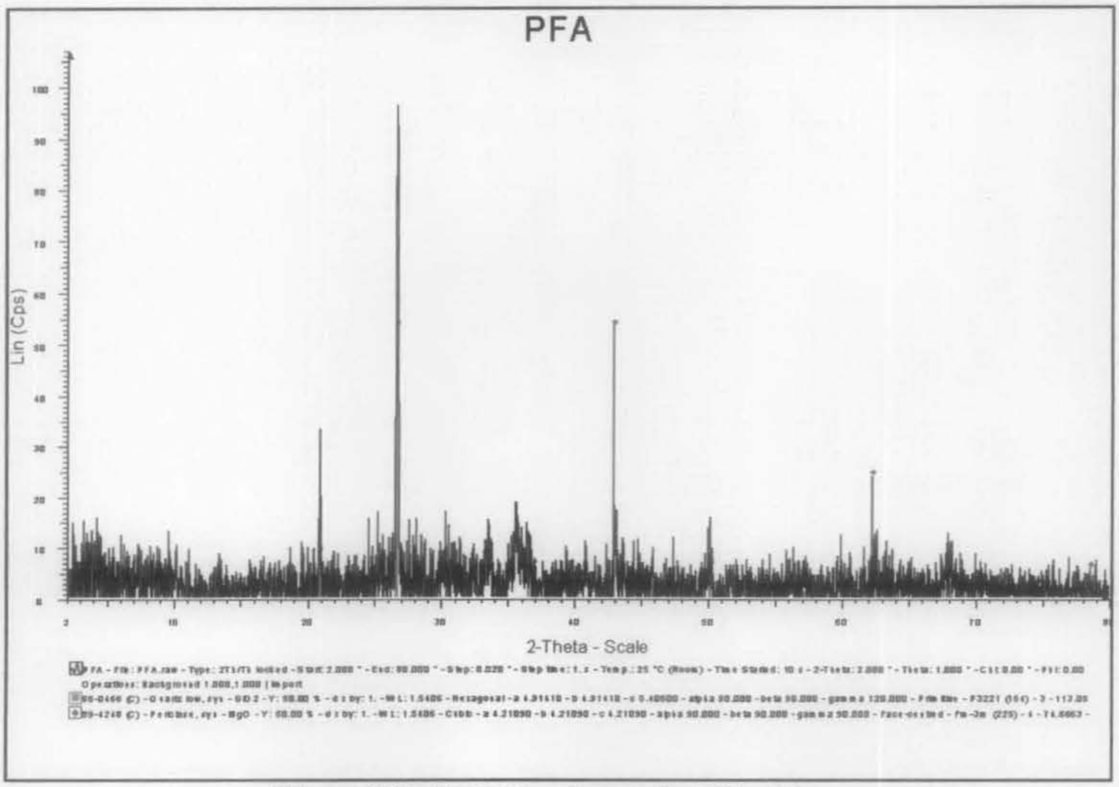

Figure D5 : XRD Result tested on Fly Ash

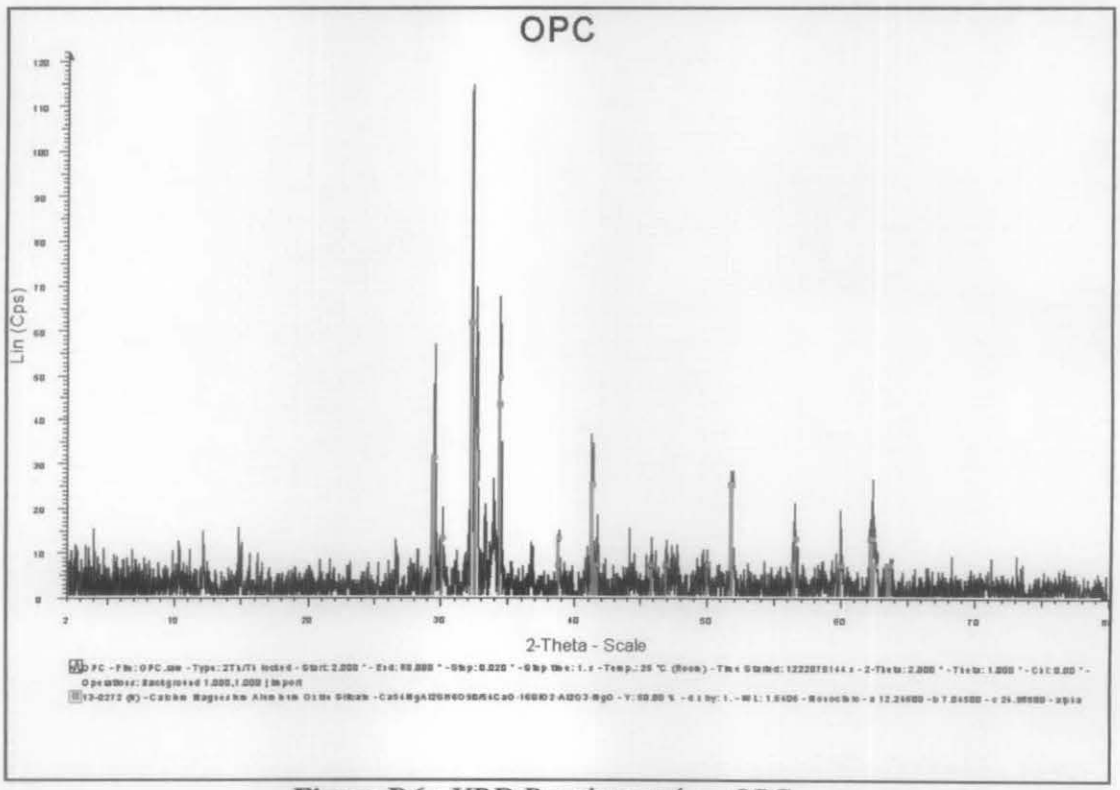

Figure D6 : XRD Result tested on OPC