The Effect of Different Filler Materials and Gradation on the Characteristics of Bituminous Mixture.

By

TENGKU ANIS AMALINA BINTI TENGKU HAMZAH

Dissertation submitted in Partial Fulfillment of
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Universiti Teknologi Petronas
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Civil Engineering Programme
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Approved:

Assoc Professor Dr Ibrahim Kamaruddin
Project Supervisor

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.

Tengku Anis Amalina Tengku Hamzah

ABSTRACT

The bituminous mixtures are a combination of bituminous materials as binders, properly graded aggregates and filler materials is sometimes added to bituminous mixtures. The increase in demands in the pavement surface with ever greater traffic levels on major roads has led to a need to improve the inherent properties of bituminous mixtures. So in order to improve the characteristic bituminous mixture, the objectives for this project are basically to access the effect of filler materials on bituminous mixture and to select the best combination of filler materials and gradation that produce the best bituminous mixtures.

Some tests have been conducted in order to fulfill the objectives of this project. For the first step, all materials have been tested to make sure that those materials are followed the JKR and BS specification. The characteristic of the mixture have tested by performing the Marshall Test.

Based on the results from physical and chemical properties of the materials used, and Marshall Test, it is concluded that combination of hydration lime and well graded is the best combination that produce the best bituminous mixture.

ACKNOWLEDGEMENTS

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Bituminous is defined as an amorphous, black or dark-colored cementitous substance, composed principally high molecular weight hydrocarbons, and soluble in carbon disulfide. Bituminous mixture is a mixture of bitumen, aggregates and filler material and is widely used in civil engineering applications, for example, as roofing materials and in the construction and maintenance of roads and other surfaces, including pavements and airport runways.

Basically bituminous mixtures are used as layers in a pavement structure to distribute stresses that can cause by loading and to protect the underlying unbound layers from the effects of water. They also provide a resilient, waterproof, load distributing medium that protects the base course from the effect of water and abrasive action of traffic.

Bituminous mixture that is used in surface courses must be designed to have sufficient stability and durability to carry the anticipated traffic loads and to withstand the detrimental effects of temperature changes and water. Additional performance-related properties have to be taken into account, in order to produce surface layers which reduce one or more of hydroplaning, noise, fatigue damage and rut formation, and which have good skid resistance.

1.2 Problem Statement

Although bitumen has been very successful as a binder, the increase in demands in the pavement surface with ever greater traffic levels on major roads has led to a need to improve the inherent properties of bituminous mixtures. So in order to over comes this problem, what filler material will provide the improvement to the bituminous mixture?

1.3 Objectives

The objectives to be achieved by the end of this project are:

- To access the effect of filler materials on bituminous mixture.
- To select the best combination of filler materials and gradation that produce the best bituminous mixtures.

1.4 Scope of Study

The scope of works will involve the studying about the filler materials itself and the potential of the filler material can help to produce highly bituminous mixtures. In order to do that, reading some related journals and doing researches about the topic will be done.

The works also involve more laboratories to get the result for this project. First of all, there's need to test bituminous, aggregate and filler before do the test for bituminous mixtures. It is because all components in bituminous mixtures must have the specific characteristic. The test consists of:

- Bituminous/binder
  - Penetration Test
  - Softening Point Test
  - Ductility Test
  - Specific Gravity Test
- Course aggregate
  - Sieve Analysis Test
  - Los Angeles Abrasion Test
  - Specific Gravity Test
- Fine aggregate
  - Sieve Analysis Test
  - Specific Gravity Test
- Filler Material
  - Specific Gravity Test
  - X-Ray Diffraction (XRD)
  - Scanning Electron Microscopy (SEM)
- Bituminous mix
  - Marshall Test

CHAPTER 2

LITERATURE REVIEW

2.1 Gradation

In bituminous mixture, gradation helps determine almost every important property including stiffness, stability, durability, permeability, workability, fatique resistance, frictional resistance and resistance to moisture damage. It is because gradation is a primary concern in bituminous mix design. The gradation that used for this project is well graded and gap graded. (See Figure 2.1)

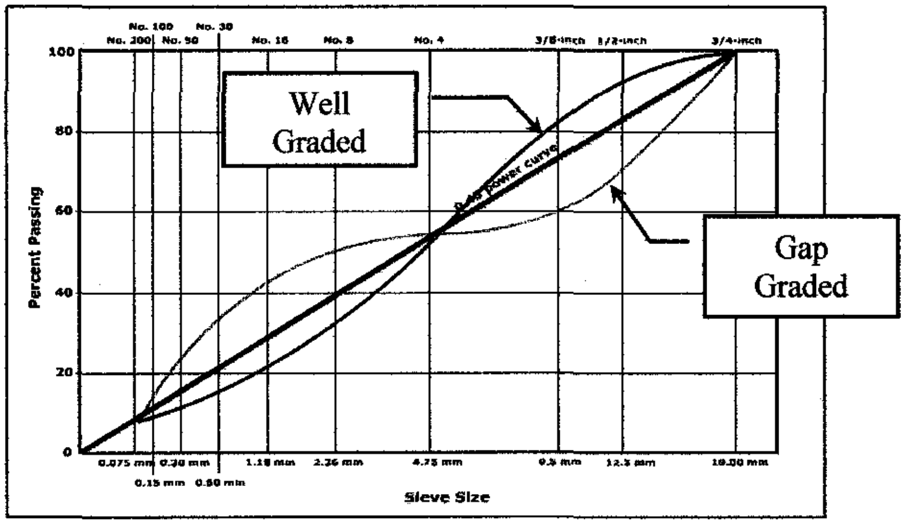

Figure 2.1: Well Graded and Gap Graded

*AASHTO Guide for the Design of Pavement Structures. American Association of State Highway and Transportation Officials, Washington, DC, 1993.

Well graded is refer to a gradation that near to the maximum density and usually used for hot rolled asphalt (HRA) surface course, the mechanical properties of which are dominated by the mortal. While gap graded is refer 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 (Mamlouk *et al.,* 1999).

2.2.1 Filler material

Filler materials (dust) consist of very fine, inert mineral matter that is added to the hot mix asphalt to improve the density and strength of the mixture. Filler materials make up less than 6 percent of the hot mix asphalt concrete by mass, and generally less than about 3 percent. Typical mineral filler completely passes a 0.060 mm (No. 30) sieve, with at least 65 percent of the particles passing the 0.075 mm (No. 200) sieve.

Filler materials consist of finely divided mineral matter such as fly ash, Ordinary Portland Cement (OPC), hydrated lime or other suitable mineral matter.

As with fine aggregate, filler can affect the binder demand. High filler content will result in a large surface area of aggregate hence increased binder demand. The filler can modify the grading of the fine aggregate to give a denser mixture with greater aggregate contact.

The portion of the filler materials that is finer than the thickness of the asphalt film and the asphalt cement binder form a mortar or mastic that contributes to improved stiffening of the mix. The particles larger than the thickness of the asphalt film behave as mineral aggregate and hence contribute to the contact points between individual aggregate particles. The gradation, shape, and texture of the mineral filler significantly influence the performance of hot mix asphalt.

2.2.1 Ordinary Portland Cement (OPC)

In ordinary Portland cement, approximately three-fourths of the mixture is some form of calcium silicate. This material is responsible for the cementing process. The chemical composition is traditionally written in an oxide notation used in ceramic chemistry. In this notation, each oxide is abbreviated to a single capital letter (Aquilina, 1999).

Determining the exact chemical composition of cement would be a very complex procedure. However, simpler oxide analysis is generally available from most cement plants on request.

Cementitious materials with reduced porosities have lower permeabilities and normally are more durable. It therefore seems probable that bituminous mixtures may reduced porosities also will show performance improvements. Cement paste porosity depends critically on the initial water-to-cement (w/c) ratio and the extent of cement hydration and the relationship between porosity and processing of cement pastes has been extensively investigated (Aquilina, 1999).

Table 2.1: Chemical Properties of OPC

Properties	**OPC**
CaO	65%
SiO_2	20%
Al_2O_3	5%
MgO	1%
Fe_2O_3	2%

*Chemical Properties from Production and Use of GGB, Civil and Marine.

2.2.2 Pulverized Fly Ash (PFA)

Fly ash is one of the residues generated in the combustion of coal. Fly ash is generally captured from the chimneys of power generation facilities, whereas bottom ash is, as the name suggests, removed from the bottom of the furnace. In the past, fly ash was generally released into the atmosphere via the smoke stack, but pollution control equipment mandated in recent decades now require that it be captured prior to release.

Fly ash has been used as substitute mineral filler in asphalt paving mixtures for many years. Mineral filler in asphalt paving mixtures consists of particles, less than 0.075 mm (No. 200 sieve) in size, that fills the voids in a paving mix and serves to improve the cohesion of the binder and the stability of the mixture. According to Meyers *et al.* (1976), most fly ash sources are capable of meeting the gradation (minus .075 mm) requirements and other pertinent physical (non-plastic) and chemical (organic content) requirements of mineral filler specifications.

Fly ash has also been shown to increase the stiffness of the asphalt matrix, improving rutting resistance and increasing mix durability. Base on Table 2.2, it is possible that some sources of fly ash that have a high lime (CaO) content may also be useful as an antistripping agent in asphalt paving mixes (Zimmer, 1970).

Table 2.2: Chemical Properties of PFA

Properties	PFA
Silica - SiO_2	49.33%
Magnesium Oxide - MgO	2.19%
Iron Oxide - Fe_2O_3	7.78%
Aluminium Oxide - Al_2O_3	20.72%
Calsium Oxide -CaO	10.26%

*This table taken from N. Volglis, G. Kakali, E. Chaniotakis and S. Tsivilis (2005) Portland-limestone cements. Their properties and hydration compared to those of other composite cements.

2.2.3 Hydrated Lime

Hydrated lime $Ca(OH)_2$ is use to treat the aggregate in bituminous mixture and to improve the performance of the asphalt/aggregate blend. The effects of lime as an anti-strip additive when lime is added directly to the aggregate are well established. Typically, dry hydrated lime is mixed with the aggregate. The lime promotes extended mixture life by improving the asphalt-aggregate bond and by reducing the susceptibility of the mixture to soften when water is absorbed within the mixture.

Adding a lime component to the aggregate is commonly done with the intention of improving the bond between the aggregate and bitumen, especially in the presence of water which has a stronger affinity for the aggregate than the bitumen does. Hydrated lime added to the aggregate is accepted as an effective antistripping agent and has been considered to have ancillary positive effects on the asphalt mixture.

According to Nicholls (1998), hydrated lime may decrease the interfacial tension between the asphalt and water, thus resulting in good adhesion. It also may help to improve the stripping resistance by interacting with the carboxylic acids in the asphalt. This interaction forms insoluble products that are readily adsorbed onto the surface of the aggregate.

Table 2.3: Chemical Properties of Hydrated Lime

Properties	**Hydrated Lime**
Calcium Hydroxide - $Ca(OH)_2$	93.5%
Calcium Carbonate- Ca CO_3	2.5%
Magnesium Oxide - MgO	2.0%
Silica - SiO2	0.23%
Aluminium Oxide - Al_2O_3	0.11%
Ferric Oxide - Fe_2O_3	0.04%
Moisture (Free) - H_2O	0.8%

*This table taken from Dallas N. Little and Jon A. Epps (2001), The Benefits of Hydrated Lime in Hot Mix Asphalt

CHAPTER 3

METHODOLOGY

This chapter focuses on the approach method in developing the project work. Basically, it will be based on research and data collection methods for the study. The purpose of this chapter is to meet the objectives which are mentioned in the first chapter.

3.1 Laboratory

All tests that conduct for bituminous, aggregates and filler materials actually to make sure that the material used for experiment are follows the BS and JKR specification.

3.1.1 Bituminous

Since a wide variety of bitumen are manufactured, it is necessary to have test to characterize different grades.

- **Penetration Test**

The penetration test is the most common control test for penetration grade bitumen. It is a measure of the consistency or hardness of the bitumen (Nicholls, 1991).

- **Softening Point Test**

The Shell Bitumen HandBook said that the consistency of a penetration grade or oxidized bitumen can also be measured by determining its softening point.

- **Ductility Test**

Ductility is the distance in cm a standard sample of bituminous material will stretch before breaking. The result of this test indicates the extent to which the material can be deformed without breaking (Nicholas, 2002).

- **Specific Gravity Test**

This purpose of this test is to determine the specific gravity and density of bituminous materials by using a pycnometer.

3.1.2 Aggregate

Since the aggregate that used for bituminous mixtures must followed specific requirement form Bristh Standard (BS), AMERICAN Society for Testing and Materials (ASTM) or Jabatan Kerja Raya Malaysia (JKR), it is necessary to have test to determine that that aggregate suitable or not to use as one of the bituminous mixture's component.

- **Sieve Analysis Test**

The aggregate's particle size distribution, or gradation, is one of its most influential characteristics. Gradation helps determine the almost important property of bituminous mix such as stiffness, stability, durability, permeability, workability, fatigue resistance, frictional resistance and etc.

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

According to Nicholas (2002), 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. The specific gravity value is expressed upon how much greater the weight of the mineral is to an equal amount of water.

- **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. A common test used to characterize toughness and abrasion resistance is the Los Angeles (L.A.) abrasion test.

- **Aggregate Impact Value Test**

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

3.1.3 Filler Material

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.

- **Sieve Analysis Test**

This sieve analysis test is to ensure that the filler passes 0.075 mm (No. 200) sieve.

- **Specific Gravity Test**

Specific gravity test is a measurement that determines the density of minerals.

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

For this test, filler materials will be scanned using nickel filtered radiation. This experiment will allow a particular mineral to be identified.

- **Scanning Electron Microscopy (SEM)**

The purpose of this testing method is to check the shape of the filler material. The procedure for this experiment start with the placing a pellet of filler and proceed with coating the sample with the gold palladium metal to reduce the oxide effect on it which will block the microscope lenses. The coated samples will be then put on microscope and analyze at certain working distance and magnification to check the shape of the fillers.

3.1.4 Marshall Test

The objective of this test is to determine the optimum bituminous content. The characteristics of bituminous mixtures can get from this test such as density, stability, porosity and flow (Nicholas, 2002).

3.2 Hazard Analysis

A hazard is a situation which poses a level of threat to life, health, property or environment. Most hazards are dormant or potential, with only a theoretical risk of harm, however, once a hazard becomes active, it can create an emergency situation while risk is the chance or probability of harm actually being done. Danger is a keyword used to denote that an indicated action will result in serious personal injury or harm. Warning is used to denote that an indicated action could result in personal injury or harm.

Hazard Analysis is a process used to determine how a device can cause hazards to occur and then reducing the risks to an acceptable level.

Physical hazards are substances which threaten the physical safety. In highway laboratory there are few physical hazards which are:

- Noise

Noise is form from unwanted sound which forms of mechanical energy caused by the vibration of the air. When sound vibrations reach the listener they are detected by a delicate mechanism in the inner ear and perceived as sound by the brain. Excessive noise has the potential to harm hearing, or even destroy it. Noise may also put stress on other parts of the body causing the abnormal secretion of hormones, the tensing of muscles and other health effects.

Noise can be controlled at the source which the equipment may be replaced by quieter models, or less noisy work procedures can be adopted. Where noise exposures cannot be reduced by other methods, hearing protection is required. This includes ear plugs and ear muffs. Hearing protection devices must be properly fitted and must be appropriate for the level, frequency and duration of the noise involved.

- Dust

Dust is a small particle of a solid substance. It is usually powdery. Dust can give big effect to the eye and breathing system.

The solution is the dust mask is required to protect their nose from dust.

- Heat

In highway lab, there are a lot of hot equipments such as oven. This hazard is come from those equipments. Heat can cause burn and scalded.

To protect the health from this hazard, the glove is required when dealing with oven and other hot equipment. And also, avoid wearing lenses when using the laboratory.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Bituminous

4.1.1 Penetration Test

Table 4.1: Result of Penetration Test

Temperature : 25^oC	Load : 100 g		Time : 5 seconds	
Sample No.	Determination 1	Determination 2	Determination 3	Mean
A	88	88	85	**87**
B	86	86	84	**85.333**

The consistency of penetration or oxidized bitumen can be measured by performing penetration test. Table 4.1 shows the result for penetration test. This bitumen is under penetration 80. It is because that the range of penetration 80 is must between ranges of 80 to 100.

4.1.2 Softening Point Test

Table 4.2: Result of Softening Point Test

Trial	Ball 1	Ball 2	Mean
1	52.4 °C	52.6^0C	**52.6 °C**
2	48 °C	48.6 °C	**48.3 °C**

Softening point can be used as a measure of consistency of the asphalt cement. In general softening does not take place at a definite temperature. Table 4.2 shows the results for softening point test. Based on the Manual on Pavement Design, the requirement for softening point of bitumen is between 45 °C to 52 °C.

4.1.3 Ductility Test

Table 4.3: Result of Ductility Test

Mould No. 1	Mould No. 2	Mould No. 3	Mean
112.3 cm	103 cm	121.5 cm	**112.3 cm**

When bitumen materials are used in the construction of roadway pavements, they are subjected to changes in temperature and other weather conditions over a period of time. These changes cause natural weathering of the material, which may lead to loss of plasticity, cracking, abnormal surface abrasion, and eventual failure of the pavement. Table 4.3 shows that the ductility for bitumen penetration 80/100 is 112.3cm. This result has been accepted because the result of shows that the value of ductility meet the BS specification where bitumen penetration 80 must exceed than 100 cm. Thus this bitumen can be used for further experiment.

4.1.4 Specific Gravity Test

Table 4.4: Result of Specific Gravity for Bitumen

			Test No.	
			1	2
Mass of pycnometer and stopper,	A	(g)	19.0	19.4
Mass of pycnometer filled with water,	B	(g)	45.3	44.8
Mass of pycnometer filled with bitumen,	C	(g)	31.0	31.5
Mass of pycnometer filled with asphalt and water,	D	(g)	45.6	45.1
Relative Density	(C – A)/ [(B – A) – (D – C)]		1.026	1.025

The specific gravity shall be expressed as the ratio of a given volume of Asphalt cement at 25 °C to that of an equal volume water at the same temperature. The specific gravity of bitumen is basically dependent on the grade of the bitumen and temperature itself. The value of the specific gravity for bitumen penetration 80 is in range of 1.020 to 1.030. Thus this bitumen can be used for further experiment.

4.2 Aggregates

4.2.1 Los Angeles (LA) Test

Table 4.5: Result for Los Angeles (LA) Test

			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	$(M_2 / M_1) \times 100\%$	%	18

The purpose of this test is to characterize toughness and abrasion. The strength of aggregate will increase with decreasing the Los Angeles abrasion value. Table 4.5 shows the result for Los Angeles abrasion test. Based on JKR specification this value should not higher then 60%.

4.2.2 Particle Density (Specific Gravity) & Water Absorption Test

Table 4.6: Specific Gravity Test for Course Aggregate

			Test No.	
			1	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	2	Average
Bulk Specific Gravity (G_{sb})	$\frac{D}{A-(B-C)}$	2.507	2.557	2.532
Bulk SSD Specific Gravity (G_{sb} SSD)	$\frac{A}{A-(B-C)}$	2.529	2.577	2.553
Apparent Specific Gravity (G_{sa})	$\frac{D}{D-(B-C)}$	2.564	2.609	2.587
Water absorption (% of dry mass)	$\frac{100(A-D)}{D}$	0.882	0.784	0.833

Table 4.7: Specific Gravity Test 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
Bulk Specific Gravity (G_{sb})	$\frac{D}{A-(B-C)}$	2.552	2.545	2.5485
Bulk SSD Specific Gravity (G_{sb} SSD)	$\frac{A}{A-(B-C)}$	2.562	2.560	2.561
Apparent Specific Gravity (G_{sa})	$\frac{D}{D-(B-C)}$	2.578	2.583	2.501
Water absorption (% of dry mass)	$\frac{100(A-D)}{D}$	0.404	0.591	0.498

The specific gravity may be affected to a well performing and durable asphalt mix. The water absorption of asphalt cement is an important factor in asphalt mixtures because water absorption can be one of the indicators to measure asphalt absorption. A highly absorptive aggregate could lead to a low durability asphalt mix. JKR Manual on Pavement Design has specified that requirement for water absorption for coarse aggregate should not more than 2%.

Table 4.6 and 4.7 shows the result for the specific gravity for course and fine aggregates. These results have been accepted since the results for water absorption for aggregate is below 2%. Thus this aggregate can be used for further experiment used.

4.2.3 Aggregate Impact Value Test

Table 4.8: Result for Aggregate Impact Value Test

		Test No.	
		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

From BS 812: Part 112, the aggregate impact value (AIV) is a strength value of an aggregate that is determined by performing the Aggregate Impact Test on a sample of the aggregate. 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), for granite must 9 and 35. Aggregate Impact Values and Aggregate Crushing Values are often numerically very similar, and indicate similar aggregate strength properties. Table 4.8 shows the result for aggregate impact value test for granite. The mean aggregate impact value for granite was 23.9% which is between 9 and 35. Thus this aggregate can be used for further experiment used.

4.3 Filler Material

4.3.1 Ordinary Portland Cement (OPC)

Table 4.9: Specific Gravity Test for OPC

Run	Volume (cm^3)	Density (g/cm^3)
1	1.1322	3.3348
2	1.1354	3.3252
3	1.1413	3.3081
Average	1.1363	**3.3227**

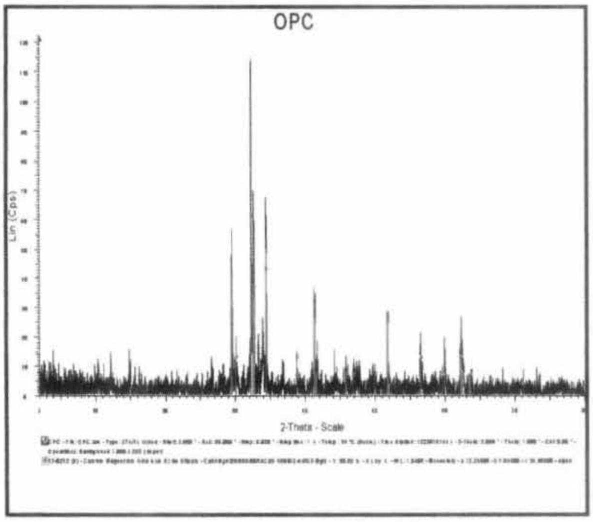

Figure 4.1: XRD Result for Ordinary Portland Cement (OPC)

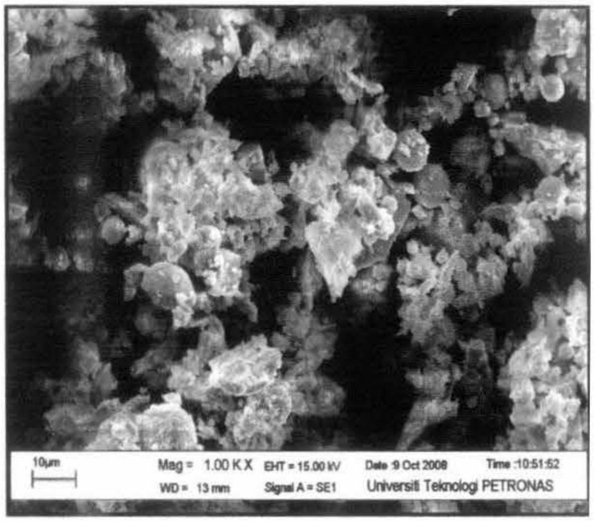

Figure 4.2: SEM Result for Ordinary Portland Cement (OPC)

Table 4.9 shows the specific gravity for OPC. The purpose to perform XRD test is to determine the particle mineral in the OPC. Figure 4.1 shows the result of XRD for OPC which contain of Calsium Oxide (CaO) in the OPC which important to help OPC to act as anti stripping agent. Figure 4.2 shows the result of SEM for OPC. OPC have irregular shape which gives more grip in mixture and make the mixture strong.

4.3.2 Pulverized Fly Ash (PFA)

Table 4.10: Specific Gravity Test for PFA

Run	Volume (cm^3)	Density (g/ cm^3)
1	1.6755	2.8511
2	1.6795	2.8444
3	1.6854	2.8344
Average	1.6801	**2.8433**

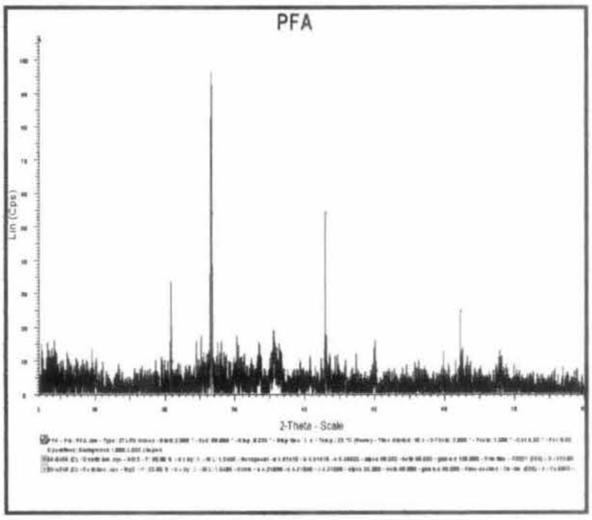

Figure 4.3: XRD Result for Pulverized Fly Ash (PFA)

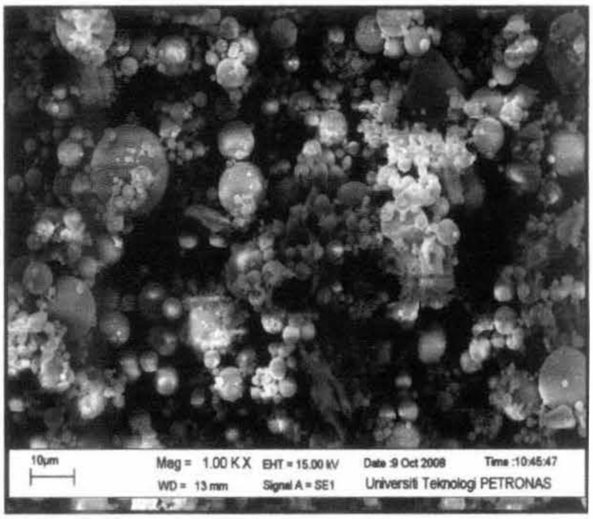

Figure 4.4: SEM Result for Pulverized Fly Ash (PFA)

Table 4.10 shows the specific gravity for PFA which is 2.8433 g/ cm^3. Figure 4.3 shows the result of XRD for PFA which contain of Silica (SiO_2) in the PFA. Figure 4.4 shows the result of SEM for PFA. PFA have sphere shape which gives less grip in mixture.

4.3.3 Hydrated Lime

Table 4.11: Specific Gravity Test for Hydrated Lime

Run	Volume (cm^3)	Density (g/cm^3)
1	0.8870	2.7245
2	0.8834	2.7671
3	0.8772	2.7549
Average	0.8792	**2.7487**

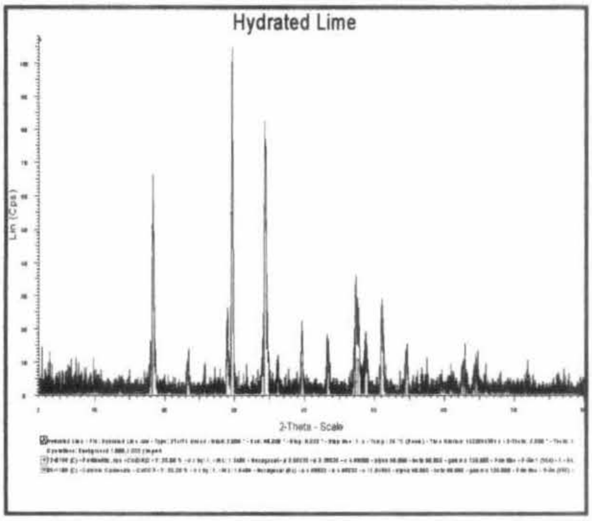

Figure 4.5: XRD Result for Hydrated Lime

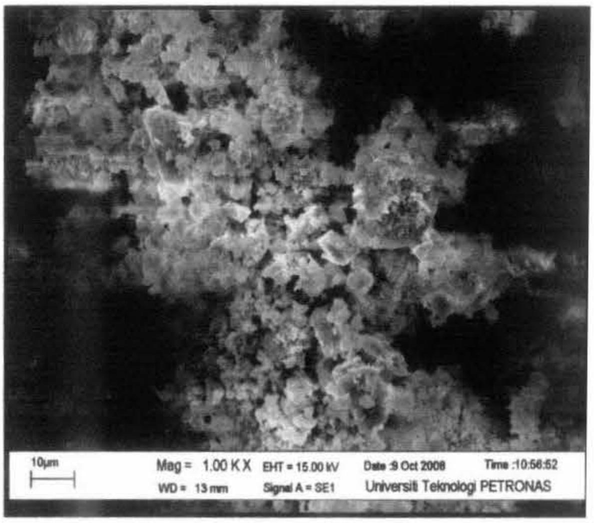

Figure 4.6: SEM Result for Hydrated Lime

Table 4.11 shows the specific gravity for hydrated lime. Figure 4.5 shows the result of XRD for hydrated lime which contain of Calcium Hydroxide ($Ca(OH)_2$) and Calcium Carbonate ($CaCO_3$) in the hydrated lime which important to treat the aggregate in bituminous mixture and to improve the performance of the asphalt/aggregate blend. It also help hydrated lime act as an anti-strip additive. Figure 4.6 shows the result of SEM for hydrated lime. Hydrated lime has irregular shape which gives more grips in mixture and makes the mixture strong.

4.4 Marshall Test

Bitumen Grade: 80/100

Specific Gravity of Bitumen: 1.03

Specific Gravity of Course Aggregate: 2.56

Specific Gravity of Fine Aggregate: 2.55

Specific Gravity of Filler: a) Ordinary Portland Cement - 3.32

b) Pulverized Fly Ash - 2.84

c) Hydrated Lime - 2.75

Gap Graded

Course Aggregate = 35 %, 420g

Fine Aggregate = 55 %, 660g

Filler = 10 %, 120g

Well Graded

Course Aggregate = 42 %, 504g
Fine Aggregate = 50 %, 600g
Filler = 8 %, 9g

Table 4.12: Stability of the Mixture

Bitumen Content	OPC		Fly Ash		Lime	
	Well	Gap	Well	Gap	Well	Gap
4.5	3.58		7.06		11.01	
5	4.63		7.22		11.17	
5.5	6.02		6.98		9.33	
6	5.18	3.94	6.75	4.91	7.8	9.12
6.5	4.56	4.79	6.57	7.28	7.5	10.08
7		5.9		7.32		7.61
7.5		5.84		6.76		6.24
8		5.59		5.92		5.65

Table 4.13: Unit Weight of the Mixture

Bitumen Content	OPC		Fly Ash		Lime	
	Well	Gap	Well	Gap	Well	Gap
4.5	2.19		2.26		2.23	
5	2.24		2.26		2.25	
5.5	2.27		2.26		2.26	
6	2.26	2.26	2.29	2.21	2.27	2.24
6.5	2.24	2.27	2.3	2.27	2.28	2.26
7		2.29		2.3		2.25
7.5		2.28		2.28		2.23
8		2.27		2.27		2.22

Table 4.14: Porosity of the Mixture

Bitumen Content	OPC		Fly Ash		Lime	
	Well	Gap	Well	Gap	Well	Gap
4.5	8.75		5.83		7.29	
5	6.3		5.25		5.67	
5.5	4.22		4.64		5.49	
6	3.83	4.26	2.98	5.53	3.82	4.68
6.5	3.86	2.58	1.52	3.44	2.58	3
7		1.3		1.08		3.02
7.5		0.87		1.3		3.04
8		0.87		0.44		3.2

Table 4.15: Flow of the Mixture

Bitumen Content	OPC		Fly Ash		Lime	
	Well	Gap	Well	Gap	Well	Gap
4.5	1.01		1.77		2.52	
5	1.12		2.21		2.8	
5.5	1.81		2.83		3.47	
6	1.98	0.76	2.96	1.97	3.68	2.25
6.5	2.12	1.27	3.31	2.7	3.92	2.37
7		1.36		2.93		2.84
7.5		1.9		3.05		3.07
8		2.53		3.41		3.59

Table 4.16: Void in Mineral Aggregate of the Mixture

Bitumen Content	OPC		Fly Ash		Lime	
	Well	Gap	Well	Gap	Well	Gap
4.5	20.17		15.69		17	
5	18.78		16.32		16.69	
5.5	18.12		16.57		16.58	
6	18.92	19.64	16.28	19.98	17.02	18.7
6.5	20.06	19.36	16.18	19.09	17.09	18.17
7		19.08		17.73		19.21
7.5		19.87		19		19.76
8		20.65		19.44		19.98

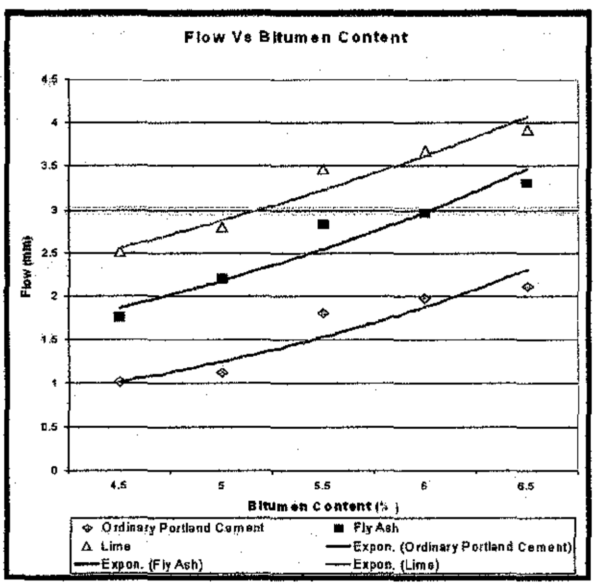

Figure 4.7: Flow vs Bitumen Content (Well Graded)

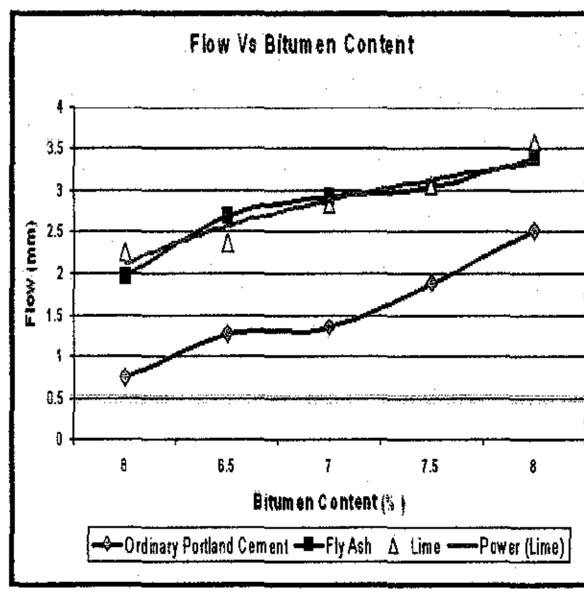

Figure 4.8: Flow vs Bitumen Content (Gap Graded)

The value of flow can be determined from conducting Marshall Test. The flow is the total movement of the sample as the load is increased from zero to the maximum. The value of flow should be increase proportionally to load. Figure 4.7 and 4.8 shows the results of the flow.

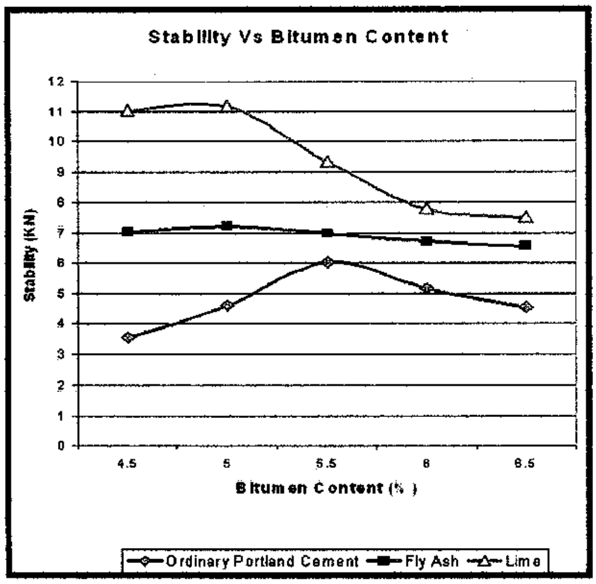

Figure 4.9: Stability vs Bitumen Content (Well Graded)

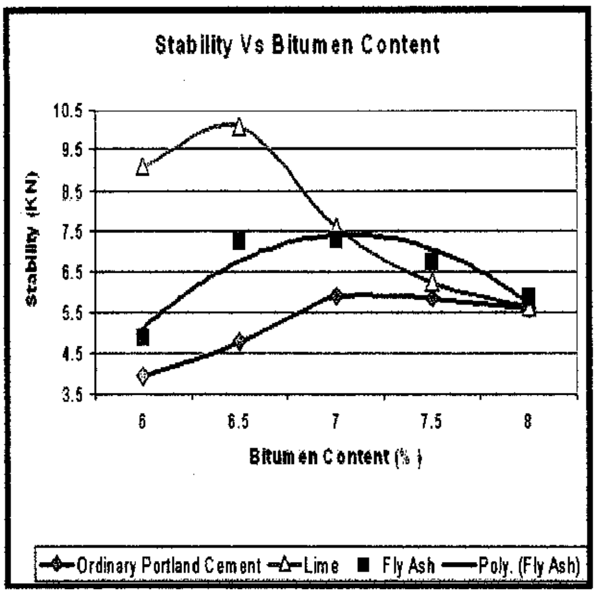

Figure 4.10: Stability vs Bitumen Content (Gap Graded)

<u>Maximum value for Stability</u>

Well Graded and Ordinary Portland Cement = 6.02 kN

Well Graded and Pulverized Fly Ash = 7.22 kN

Well Graded and Hydrated Lime = 11.33 kN

Gap Graded and Ordinary Portland Cement = 5.90 kN

Gap Graded and Pulverized Fly Ash = 7.32 kN

Gap Graded and Hydrated Lime = 10 kN

The stability of the sample is the maximum load resistance that the sample will achieve at 60 °C. Figure 4.9 and 4.10 shows the results of the stability for four combinations. All the values of the stability are followed the ASTM requirement which are the minimum value for medium traffic surface is 5kN and heavy traffic surface is 8kN. This means that combination with hydrated lime suitable used for heavy traffic surface. It is because the maximum values for that combination greater than 8kN, while for the combination with Ordinary Portland Cement and Pulverized Fly Ash suitable for medium traffic surface since the maximum value higher than 5kN but smaller than 8kN. From the graphs, combination of well graded and hydrated lime having the highest value of stability than other combinations.

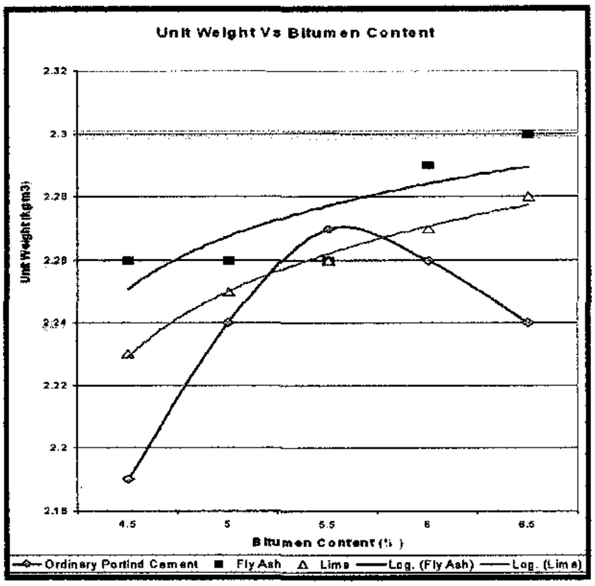

Figure 4.11: Unit Weight vs. Bitumen Content (Well Graded)

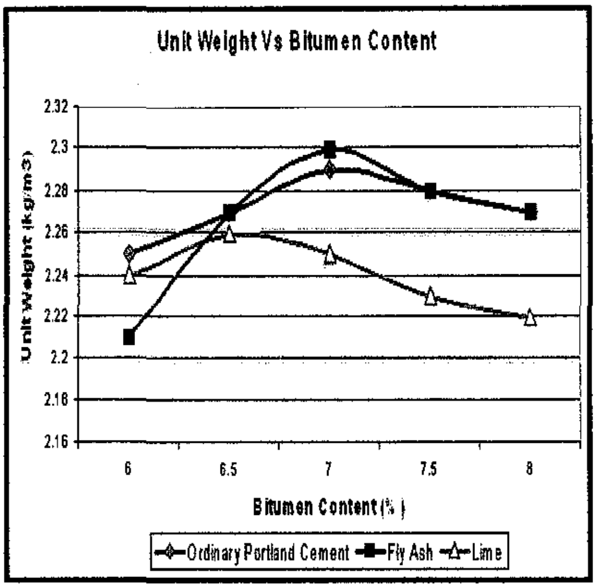

Figure 4.12: Unit Weight vs. Bitumen Content (Gap Graded)

<u>Maximum value for Unit Weight</u>

Well Graded and Ordinary Portland Cement = 2.27 kg/m^3

Well Graded and Pulverized Fly Ash = 2.29 kg/m^3

Well Graded and Hydrated Lime = 2.28 kg/m^3

Gap Graded and Ordinary Portland Cement = 2.26 kg/m^3

Gap Graded and Pulverized Fly Ash = 2.30 kg/m^3

Gap Graded and Hydrated Lime = 2.29 kg/m^3

The value of unit weight of the sample is determined usually by weighing the sample in air and water. Figure 4.11 and 4.12 shows the results for four combinations of mixtures. The higher the density, the stronger the mixture will be. From the graphs, combination of well graded and pulverized fly ash having the highest value of unit weight than other combinations.

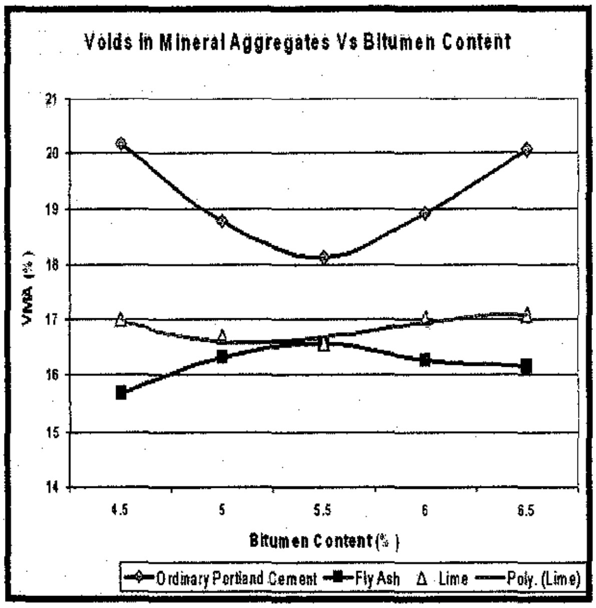

Figure 4.13: Void in Mineral Aggregate vs. Bitumen Content (Well Graded)

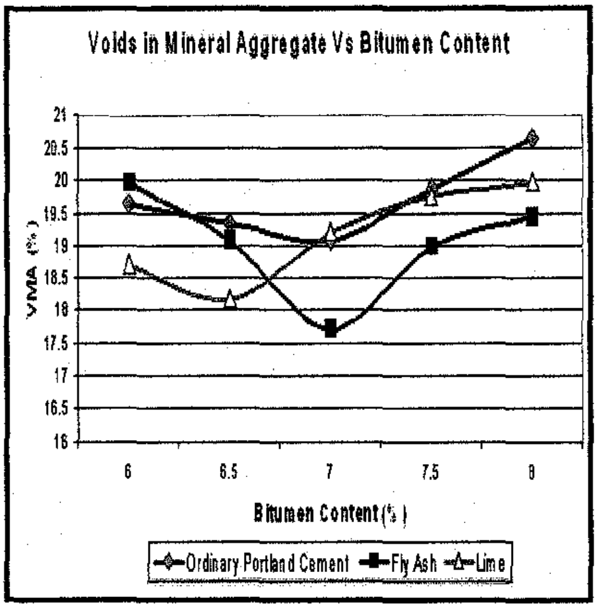

Figure 4.15: Void in Mineral Aggregate vs. Bitumen Content (Gap Graded)

Minimum value for Void in Mineral Aggregates (VMA)

Well Graded and Ordinary Portland Cement = 18.12 %

Well Graded and Pulverized Fly Ash = 15.69 %

Well Graded and Hydrated Lime = 16.5 %

Gap Graded and Ordinary Portland Cement = 19.08 %

Gap Graded and Pulverized Fly Ash = 17.73 %

Gap Graded and Hydrated Lime = 18.17 %

Void in Mineral Aggregates (VMA) is the percentage of void spaces between the granular particles in compacted bituminous mixtures. Figure 4.13 and 4.14 shows the results of VMA for four combinations of mixtures. The lower the VMA, the stronger the mixture will be. When voids are high, it is likely that the permeability of the pavement will also high, which will allow water and air to circulate through the pavement. It is lead to premature hardening of the bituminous. From the graphs, combination of well graded and pulverized fly ash having the lowest value than other combinations.

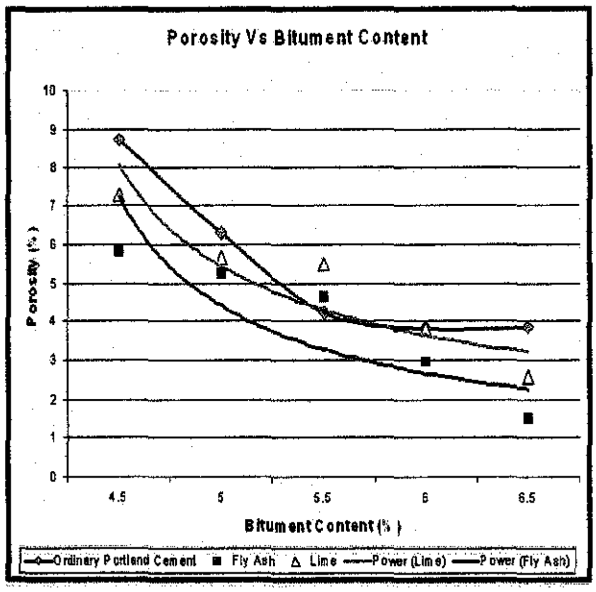

Figure 4.15: Porosity vs Bitumen Content (Gap Graded)

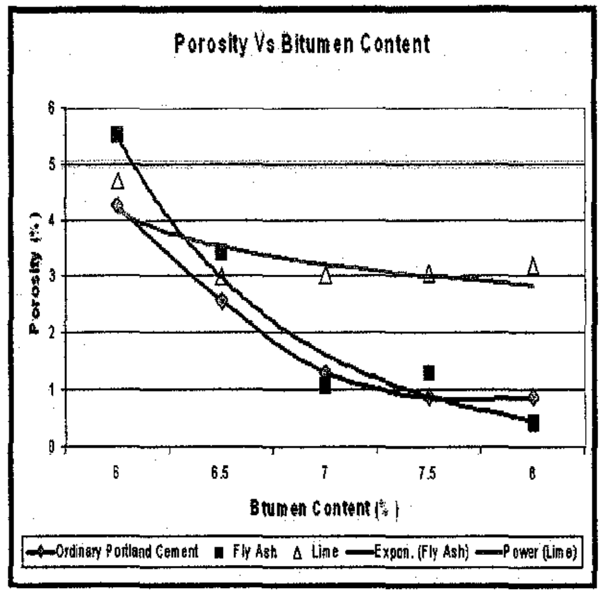

Figure 4.16: Porosity vs Bitumen Content (Well Graded)

Porosity is the percentage between the volume of the small air voids between the coated particles and the total volume of the mixtures. The all values of the stability are followed the ASTM requirement which is the percentage of air void cannot be less than 3 and bigger than 5. Figure 4.15 and 4.16 shows the result of the porosity for all the combination of the mixtures. It is mean that the mixtures from all combination meet the ASTM requirement.

Optimum Bitumen Content

Optimum bitumen content can be determined by using four graphs which are Stability vs. Bitumen Content, Unit Weight vs. Bitumen Content, Porosity vs. Bitumen Content and Void in Mineral Aggregates (VMA) vs. Bitumen Content. For stability and unit weight, bitumen content will be taken from the maximum value while for VMA, bitumen content based on the minimum value of the VMA. For porosity, bitumen content based on 4 % of the porosity. It is because the requirement for porosity is 3 to 5 percent. 4 % is the best value for porosity.

Table 4.17: Optimum Bitumen Content - OPC Well Graded

Stability	5.5
Unit Weight	5.6
Porosity	5.6
VMA	5.5
Optimum bitumen content	5.55

Table 4.18: Optimum Bitumen Content – OPC Gap Graded

Stability	7
Unit Weight	7.1
Porosity	6.1
VMA	7
Optimum bitumen content	6.8

Table 4.19: Optimum Bitumen Content - PFA Well Graded

Stability	5
Unit Weight	6.5
Porosity	5.12
VMA	4.5
Optimum bitumen content	5.28

Table 4.20: Optimum Bitumen Content – PFA Gap Graded

Stability	7
Unit Weight	7
Porosity	6.06
VMA	7
Optimum bitumen content	6.77

Table 4.21: Optimum Bitumen Content – Lime Well Graded

Stability	4.65
Unit Weight	6.5
Porosity	5.6
VMA	5.1
Optimum bitumen content	5.46

Table 4.22: Optimum Bitumen Content – Lime Gap Graded

Stability	4.65
Unit Weight	6.5
Porosity	5.6
VMA	5.1
Optimum bitumen content	5.46

CHAPTER 5

CONCLUSION

According to the result, it is concluded that combination of lime and well graded is the best combination to improve the bituminous mixture. The best combination is when the optimum bitumen content is the lowest than other. From result, the lowest optimum content is combination of pulverized fly ash and well graded. Pulverized fly ash and well graded have the highest value of unit weight and the lowest value for VMA while combination of lime and well graded has the highest value for stability. The different of unit weight and VMA between combination of lime and well graded and pulverized fly ash and well graded is so small compared to different of stability.

Besides, from the physical and chemical properties tests of filler materials also can be the reasons why the combination hydrated lime and well graded give the best improvement to bituminous mixture. From specific gravity test for filler shows that hydrated lime is the lighter and finer from others which the filler can be filled all the voids in the mixture. In the mixture designed with the filler material usually require a lower percentage by weight to obtain the same performances which are voids in mineral aggregate, stiffness, drain down and etc.

The purpose to conduct the XRD test which stands for X-Ray Diffraction is to determine the particle minerals in the filler materials which it will give the big impact to the mixture to make the better improvement. From the test, hydrated lime contain of Calcium Hydroxide ($Ca(OH)_2$) and Calcium Carbonate ($CaCO_3$) which so important to treat the aggregate in the mixture and to improve the performance of the asphalt/aggregate blend. The chemical materials inside the hydrated lime also help it to act as anti-strip additive.

The result that obtain from Scanning Electron Microscopy (SEM) test shows that the shapes of the filler materials. The shape of the filler materials is important attributes to overall performance of the mixture structure. Hydrated lime has very irregular shape than others which gives more grips in mixture and makes the mixture strong. The use of angular, nearly dimensional filler material with rough surface texture is preferred over the rounded, smooth shape of the filler material's texture. It is because the smooth shape will reduced the strength when the load is applied to the mixture. Hydrated lime have rough surfaced particles which hard and take long time to coat with binder. However, in Hot Mix Asphalt (HMA) asphalt tends to bond more effectively with rough-surfaced particles.

Thus, from the Marshall test and all the physical and chemical properties test, its conclude that the combination of lime and well graded is the best combination to improve bituminous mixture and it will help to overcome the problem occurs.

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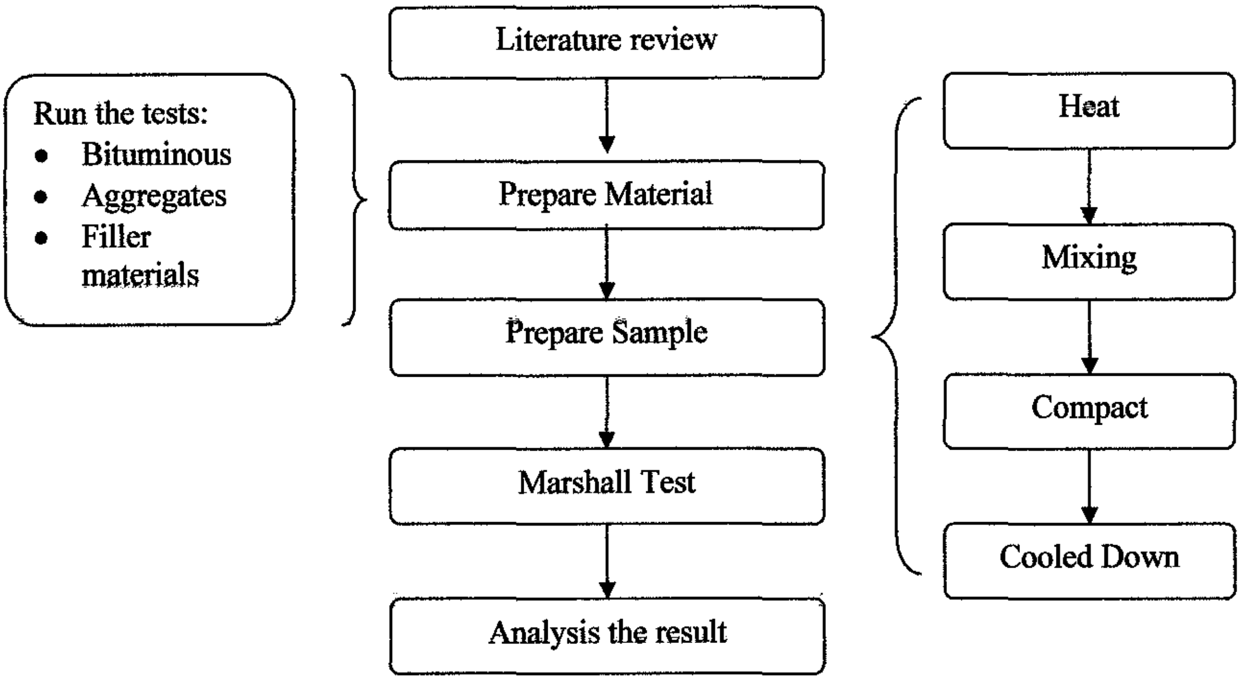
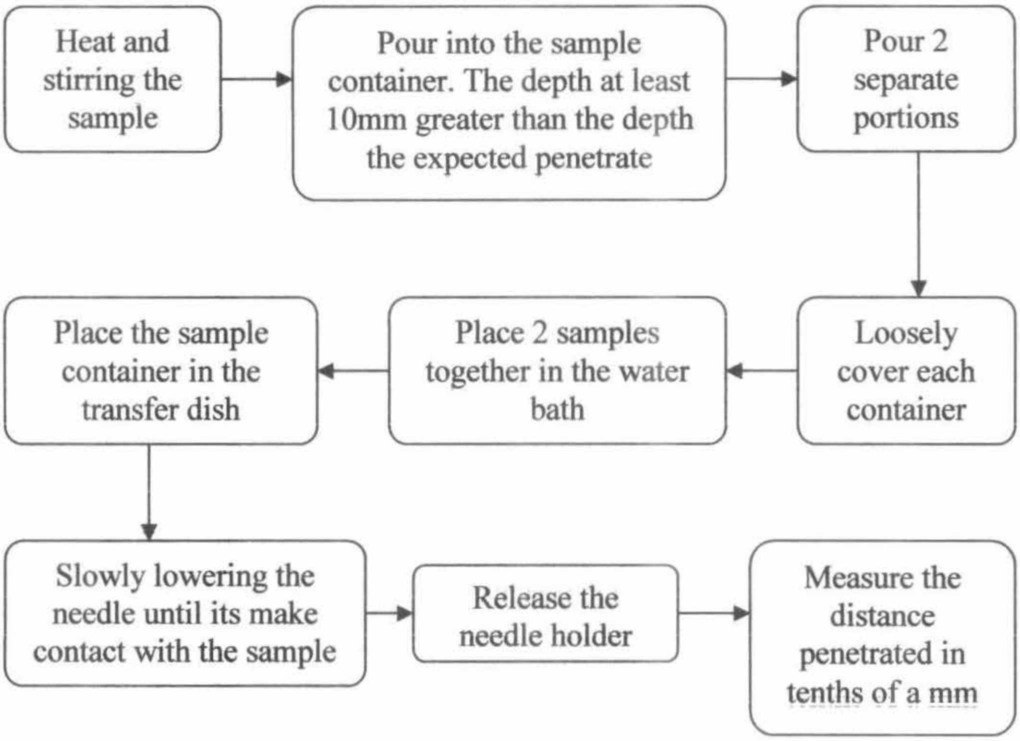
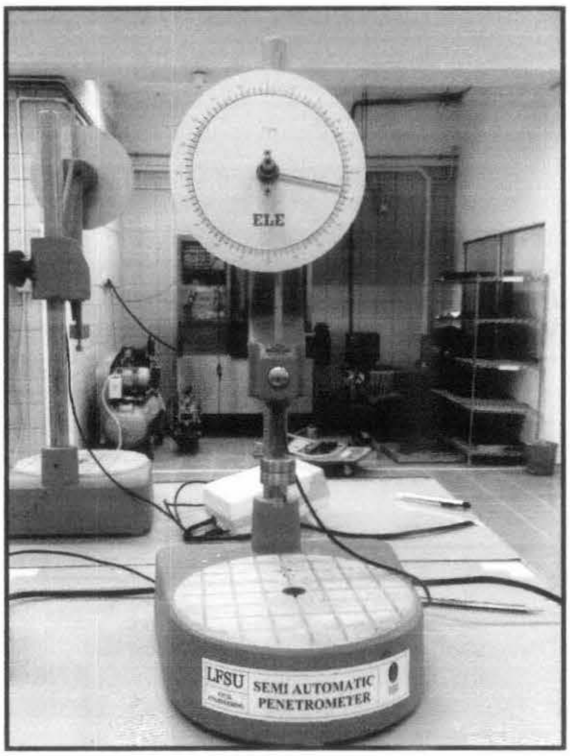
APPENDICES

APPENDIX 1: Methodology of the Project



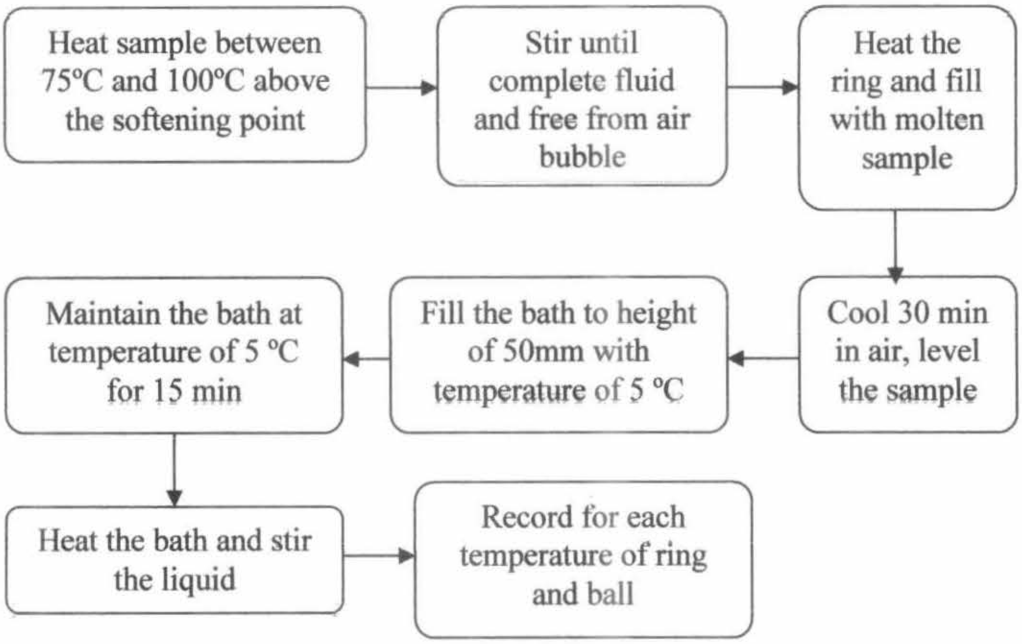
APPENDIX 2: Penetration Test

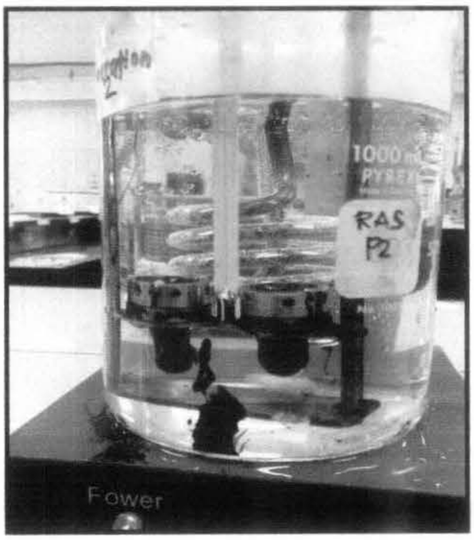




Semi Automatic Penetrometer

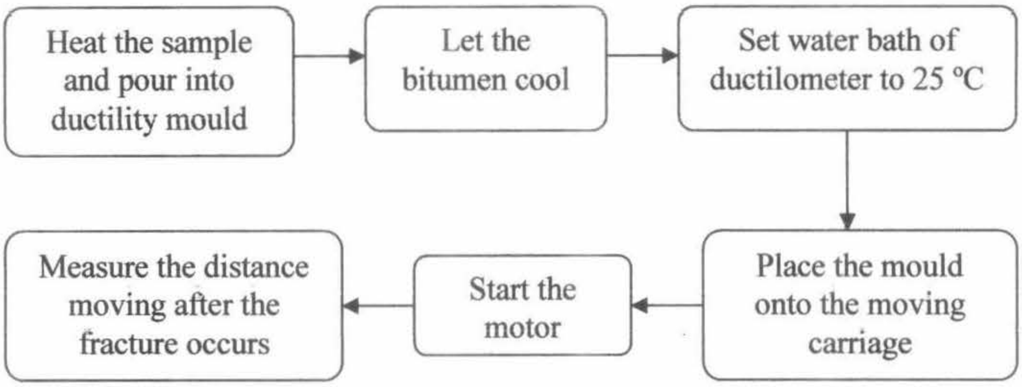
APPENDIX 3: Softening Point Test

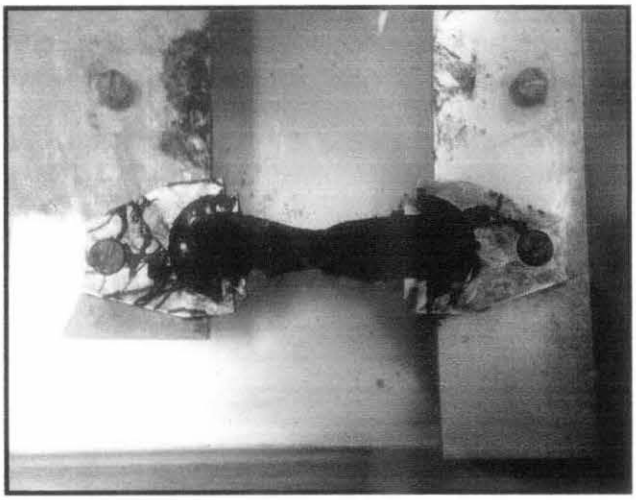




Softening Point Test

APPENDIX 4: Ductility Test





Ductility Mould

APPENDIX 5: Sieve Analysis Test

Weight the sieves

↓

Sieve the sample for 5 to 10 min

↓

Weight the sieve again

↓

Compute the percent passing each sieve

↓

Plot the semilogarithmic

Stack of Sieve in a Mechanical Sieve Shaker

APPENDIX 6: Specific Gravity Test

- Bituminous

Fill a 600 ml Griffin low form beaker with distilled water

↓

Put the beaker inside the water bath

↓

Weight the pycnometer, Mass A

↓

Remove the beaker from the water bath, fill the pycnometer with distilled water and place in the beaker and put them inside the water bath

↓

Weight the pycnometer and water, Mass B

↓

Pour sample inside the pycnometer about 3/4 and leave it cold

↓

Weight the pycnometer and sample, Mass C

↓

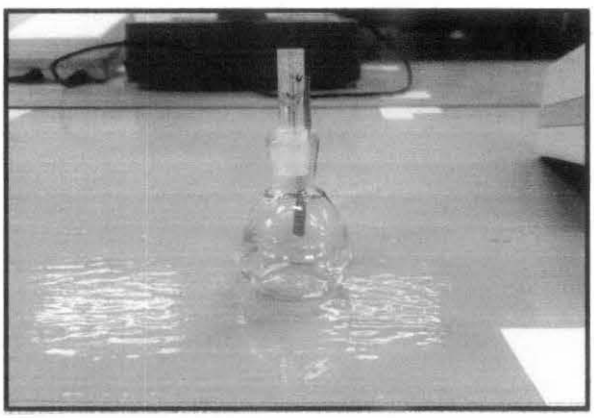
Add distiller water inside the pycnometer and put it inside the beaker

↓

After 30 min, weight the pycnometer, Mass D

↓

Calculate the particle density



Pycnometer

- Aggregate (Course and Fine)

Prepared sample in water in the glass vessel and weight it

↓

Weight the dry vessel

↓

Weight the aggregate

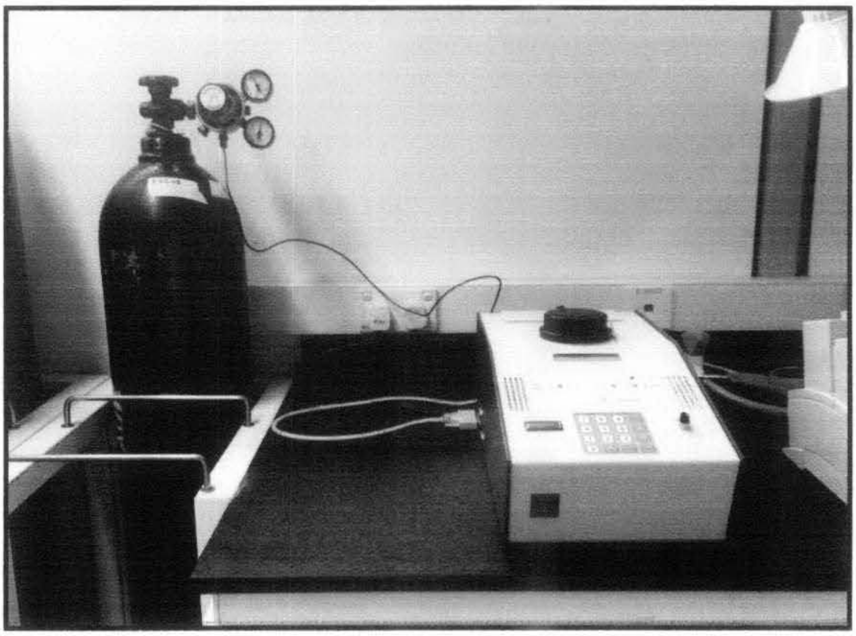
↓

Place the aggregate in the oven about 24 hours and weight it

↓

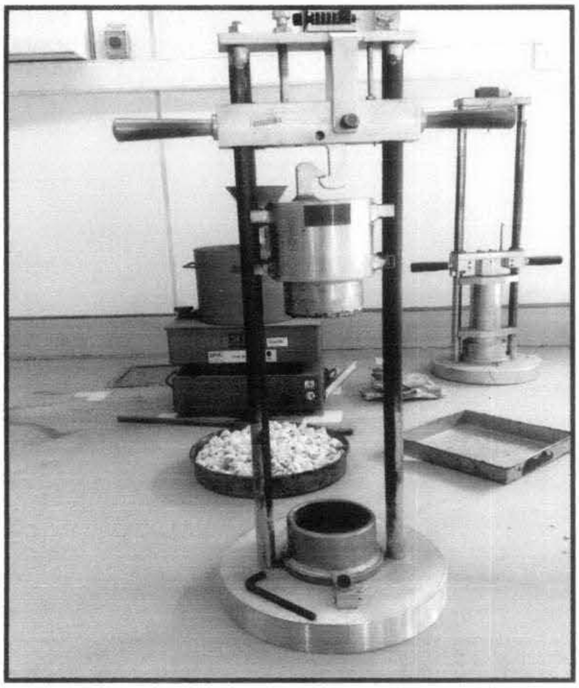
Calculate the particle density

- Filler

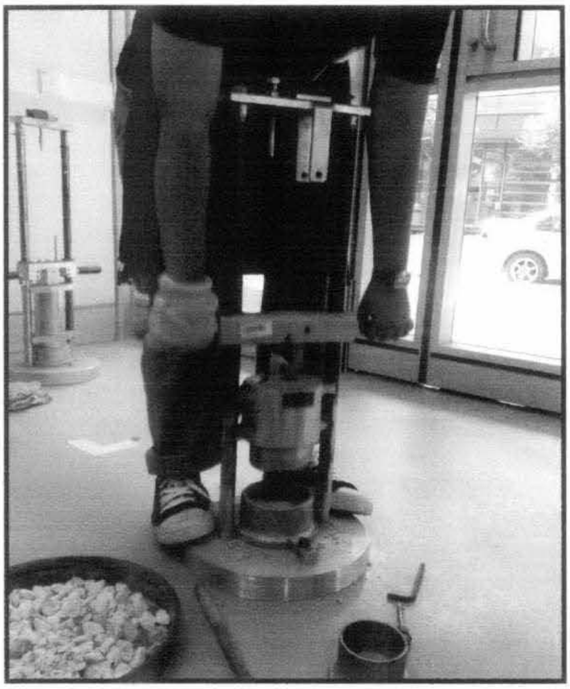


Ultrapycnometer 1000

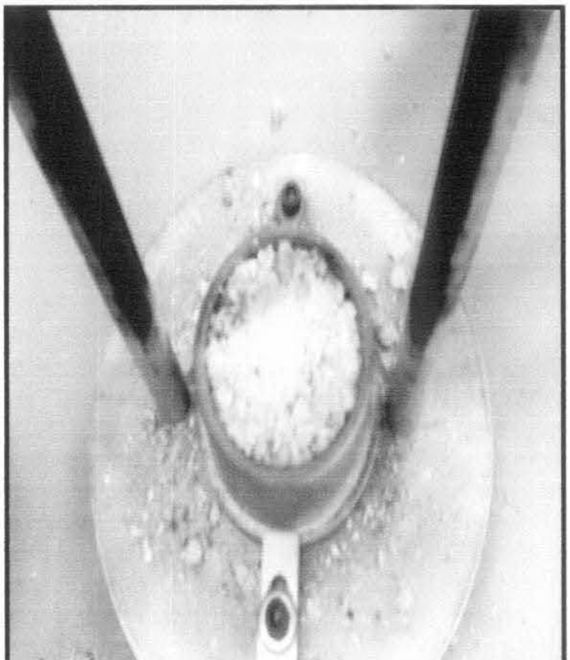
APPENDIX 7: Aggregate Impact Value (AIV) Test



AIV Equipment

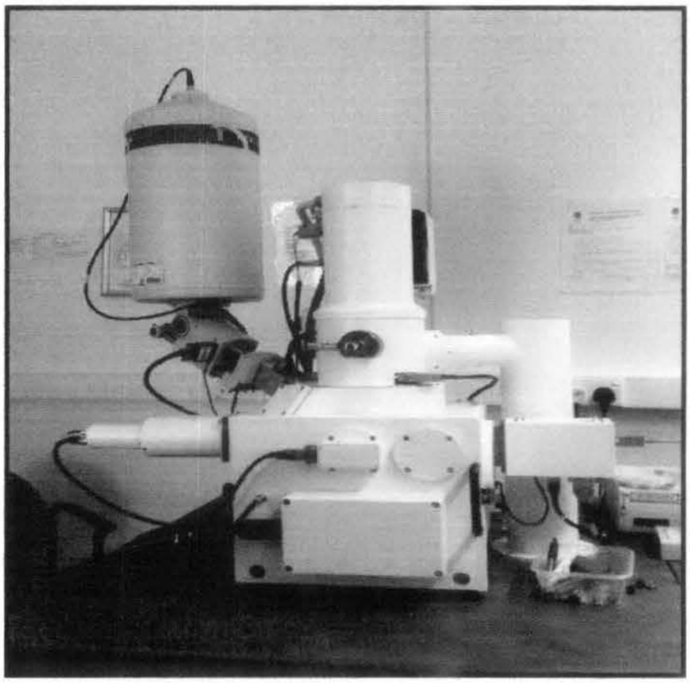


The hammer gives compaction to the specimen.

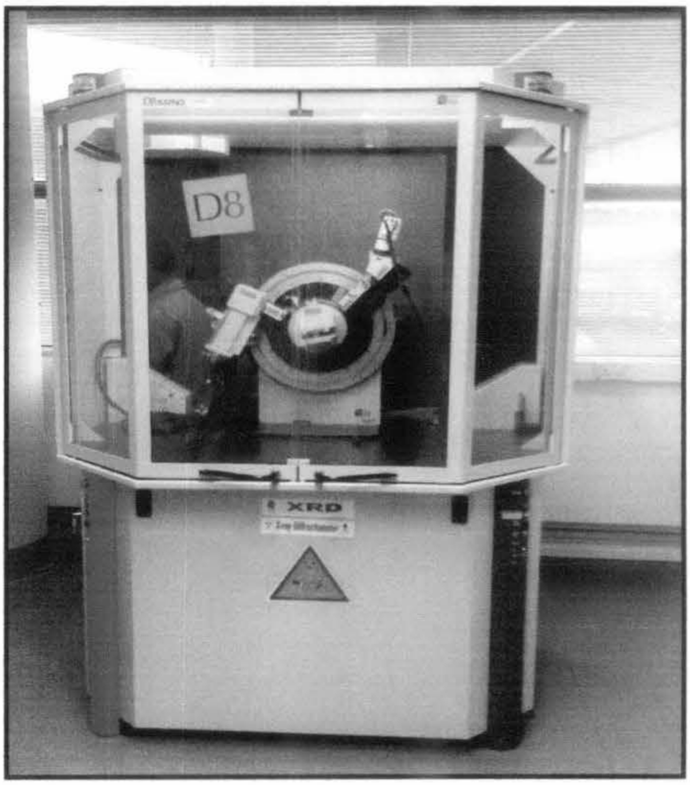


The aggregate crushed when certain amount of pressure was applied to it

APPENDIX 8: Scanning Electron Microscopy (SEM) and X-Ray Diffraction (XRD)



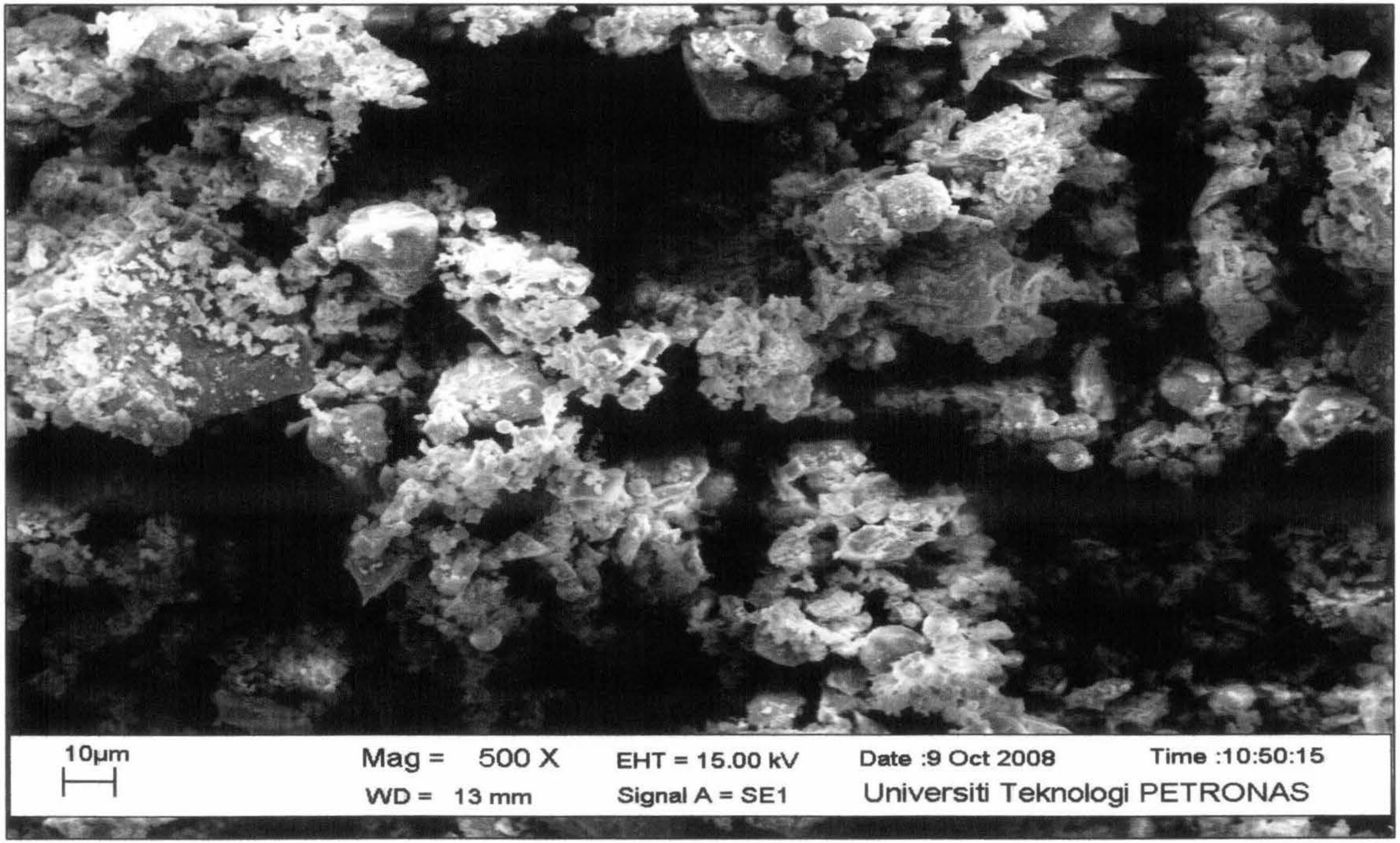
Scanning Electron Microscopy (SEM) Tests



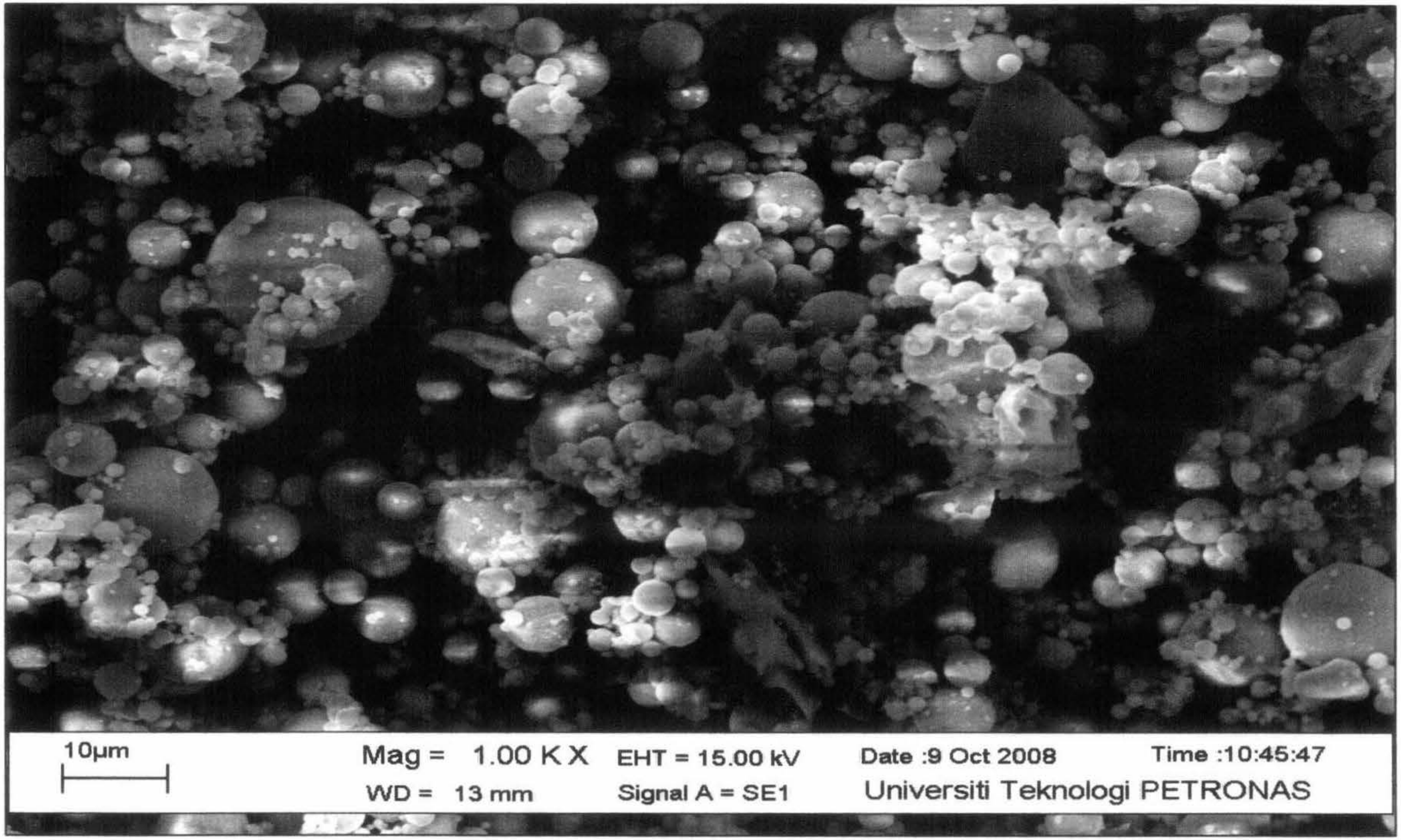
X-Ray Diffraction (XRD)

APPENDIX 9: Result SEM test for filler materials

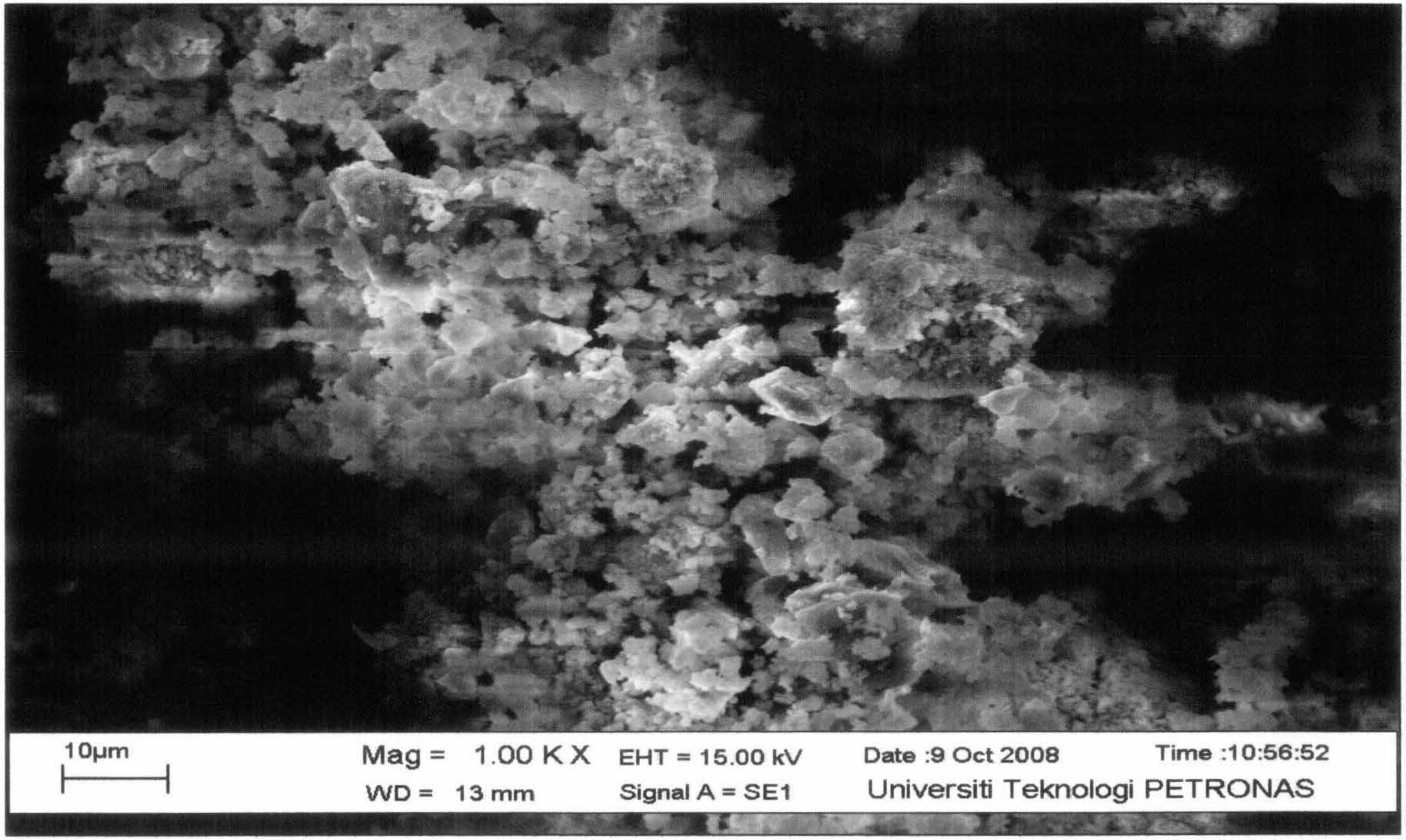
1. **OPC**



2. PFA

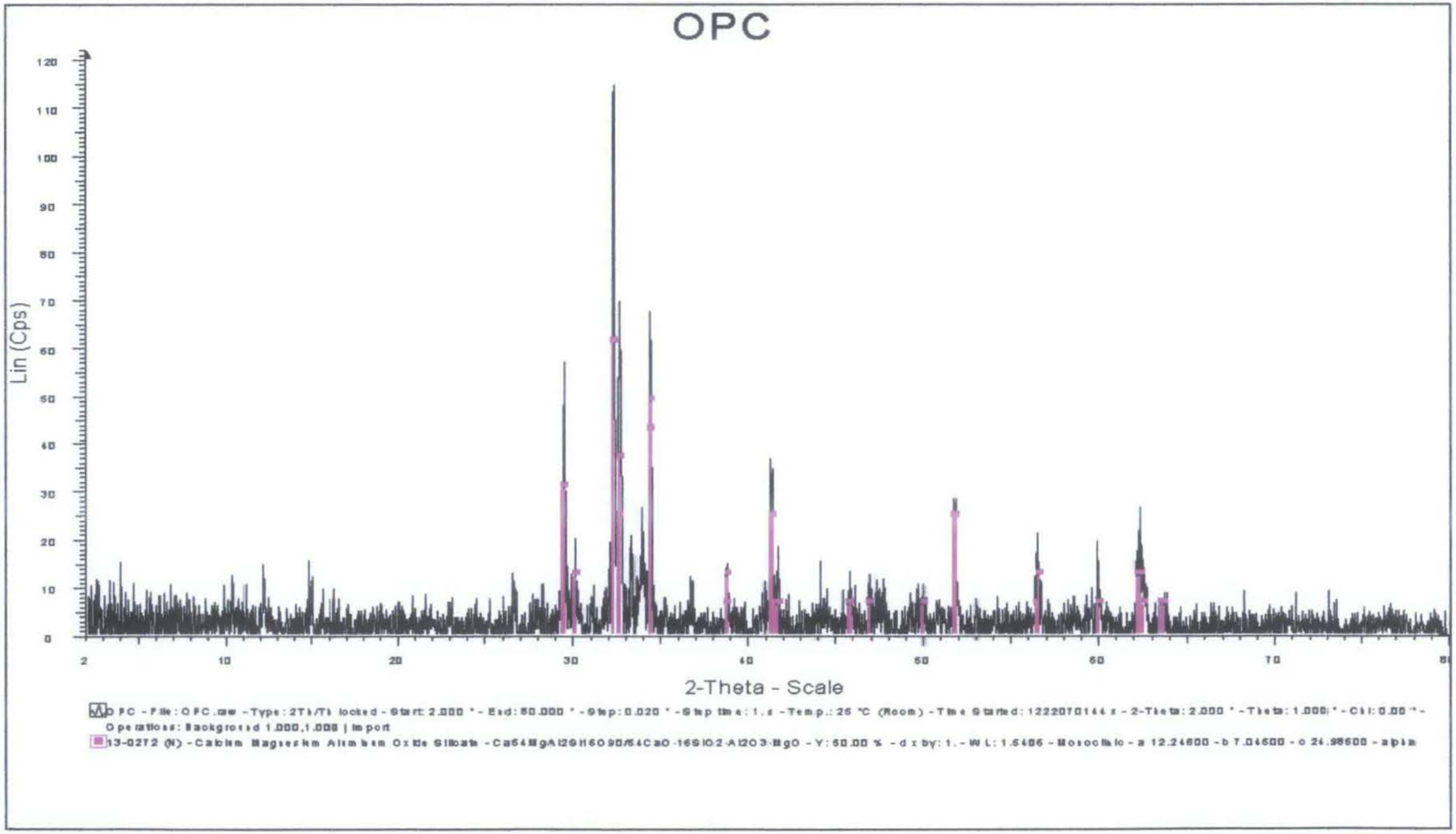

10µm
Mag = 1.00 K X
WD = 13 mm
EHT = 15.00 kV
Signal A = SE1
Date :9 Oct 2008
Time :10:45:47
Universiti Teknologi PETRONAS

3. Hydrated Lime

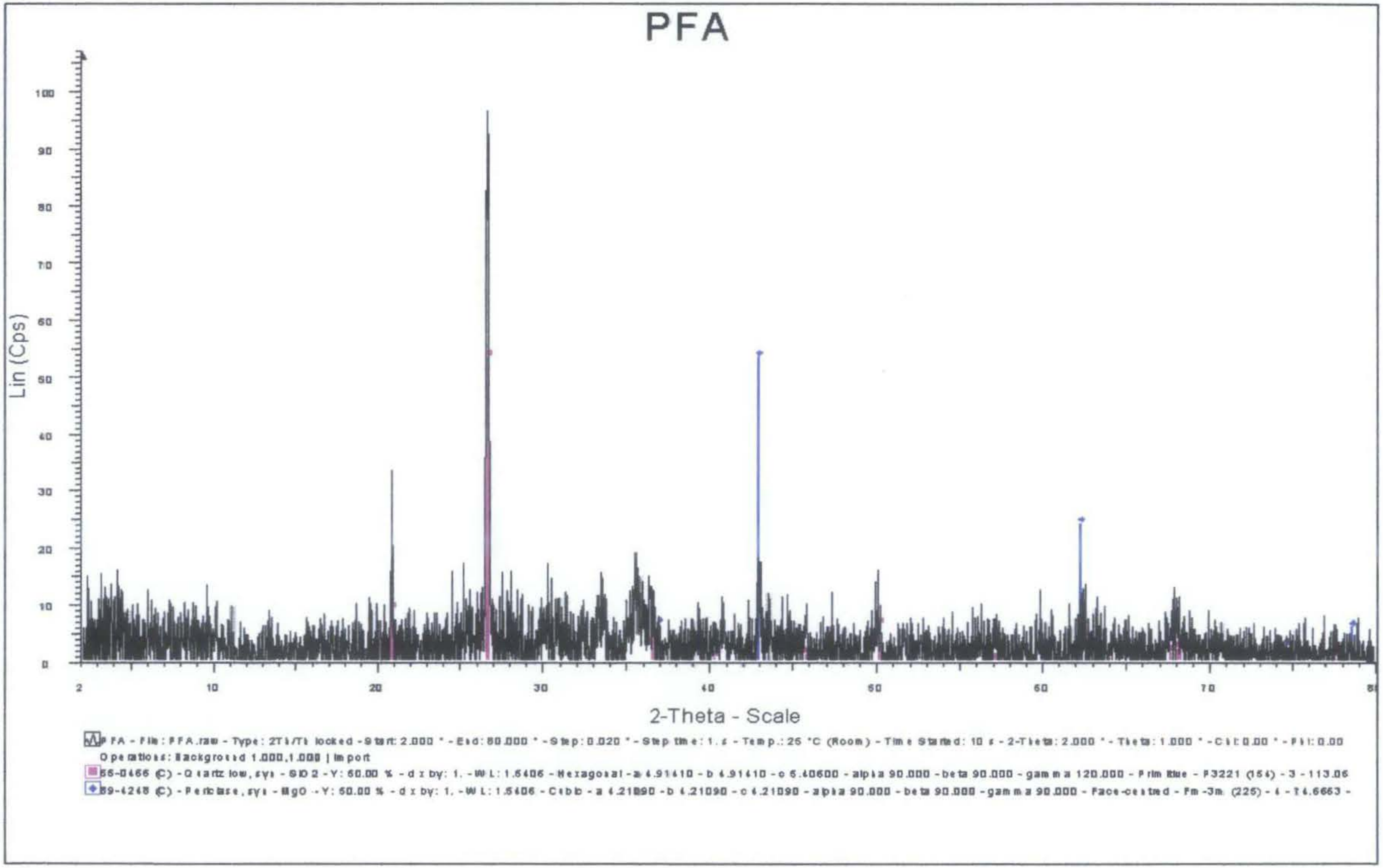


APPENDIX 10: Result XRD test for filler materials

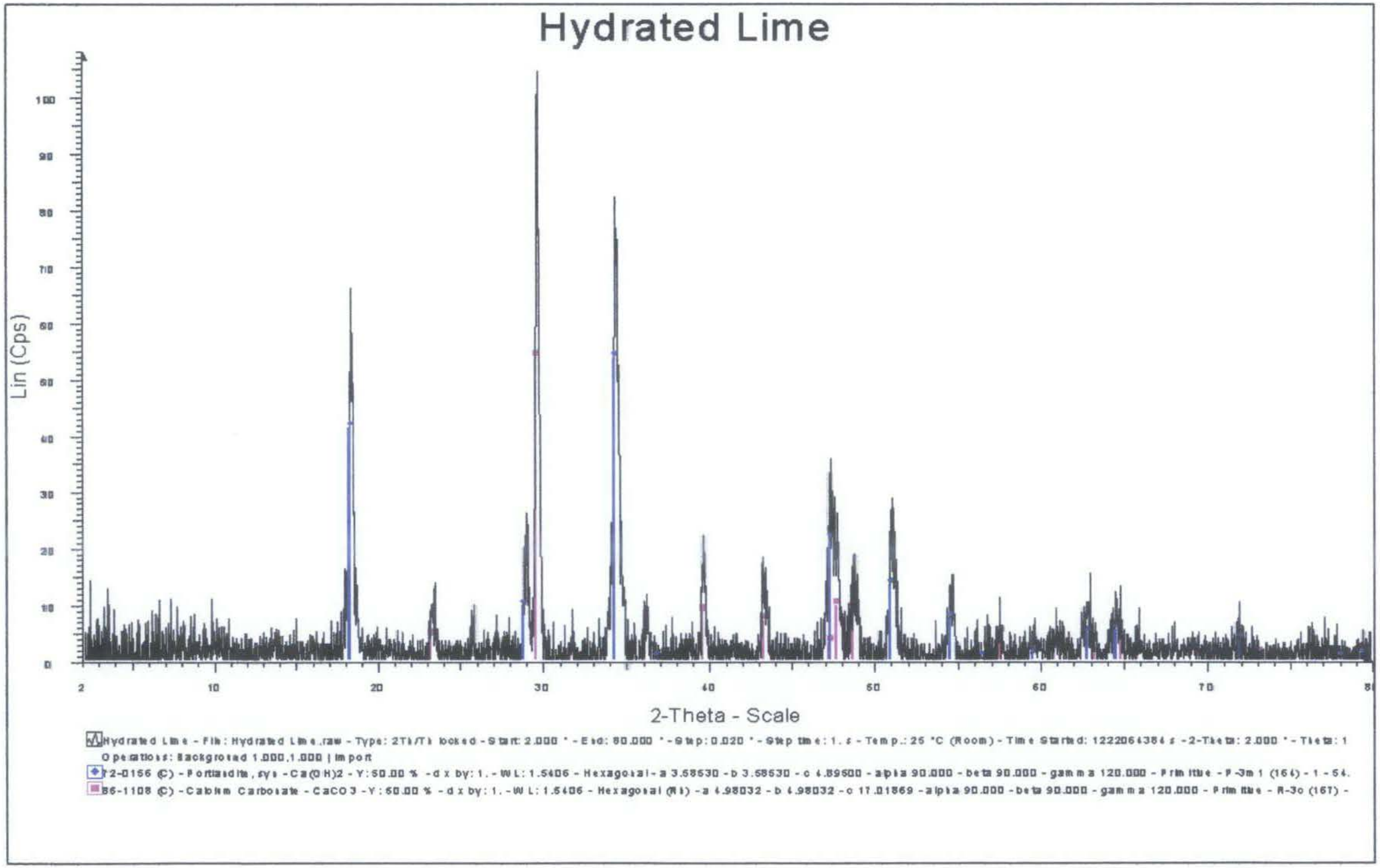
1. **OPC**



2. PFA


PFA
Lin (Cps)
2-Theta - Scale
PFA - File: PFA.raw - Type: 2Th/Th locked - Start: 2.000 ° - End: 80.000 ° - Step: 0.020 ° - Step time: 1. s - Temp.: 25 °C (Room) - Time Started: 10 s - 2-Theta: 2.000 ° - Theta: 1.000 ° - Chi: 0.00 ° - Phi: 0.00
Operations: Background 1.000,1.000 | Import
85-0465 (C) - Quartz low, syn - SiO2 - Y: 50.00 % - d x by: 1. - WL: 1.5406 - Hexagonal - a 4.91410 - b 4.91410 - c 5.40600 - alpha 90.000 - beta 90.000 - gamma 120.000 - Primitive - P3221 (154) - 3 - 113.06
89-4248 (C) - Periclase, syn - MgO - Y: 50.00 % - d x by: 1. - WL: 1.5406 - Cubic - a 4.21090 - b 4.21090 - c 4.21090 - alpha 90.000 - beta 90.000 - gamma 90.000 - Face-centred - Fm-3m (225) - 4 - 74.6663 -

3. Hydrated Lime



APPENDIX 11: Marshall Test

Marshall Test

Bituminous Mixture

APPENDIX 12: MARSHALL MIX DESIGN & TEST (ORDINARY PORLAND CEMENT AND WELL GRADED)

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

APPENDIX 13: MARSHALL MIX DESIGN & TEST (ORDINARY PORLAND CEMENT AND GAP GRADED)

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

APPENDIX 14: MARSHALL MIX DESIGN & TEST (PULVERIZED FLY ASH AND WELL GRADED)

Sample no.	Binder Content	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

APPENDIX 15: MARSHALL MIX DESIGN & TEST (PULVERIZED FLY ASH AND GAP GRADED)

Sample no.	Binder Content	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		5.53	19.74	1.44	4.91	0.89	4.37
B		71.73	1250.0	682.0	568.0	2.20	2.35	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		4.29	19.81	2.31	6.95	0.86	5.98
B		69.39	1267.5	709.5	558.0	2.27	2.33	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		0.43	17.37	2.99	8.21	0.89	7.31
B		67.69	1255.0	710.0	545.0	2.30	2.32	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		0.43	18.53	3.02	7.61	0.89	6.77
B		69.53	1265.0	707.0	558.0	2.27	2.30	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		0.87	19.68	3.43	6.55	0.89	5.83
B		69.78	1254.0	704.0	550.0	2.28	2.29	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

APPENDIX 16: MARSHALL MIX DESIGN & TEST (HYDRATED LIME AND WELL GRADED)

Sample no.	Binder Content	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

APPENDIX 17: MARSHALL MIX DESIGN & TEST (HYDRATED LIME AND GAP GRADED)

Sample no.	Binder Content	Height (mm)	Mass of Specimen		Volume (cm^3)	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	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