COMPARATIVE ANALYSIS OF HYDRATED LIME (HL) AND ORDINARY PORTLAND CEMENT (OPC) AS FILLER IN ASPHALT CONCRETE MIXTURES

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IN ASPHALT CONCRETE PAVEMENT

by

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ABSTRACT

There are many ways to improve the performance of asphalt concrete mixtures to minimize distress such as permanent deformation and fatigue on highway pavements. One of these ways is by adding fillers. Commonly used fillers that have been known as anti-stripping agent are Hydrated Lime (HL) and Ordinary Portland Cement (OPC), which both share the same predominant component, i.e. Lime (CaO). This study focuses on comparing the engineering characteristics of asphalt concrete mixtures using Hydrated Lime (HL) and Ordinary Portland Cement (OPC) as mineral fillers to improve the performance of the mixtures. The fundamental engineering properties of the mixtures were determined through the Marshall Mix design. The Optimum Bitumen Content (OBC) was then used to prepare the specimens for further performance tests. The performance test included permanent deformation tests using creep and wheel tracking tests and beam fatigue test to determine the fatigue characteristics of the mixtures. Findings of this study showed that the smaller particle size as well as the irregular shape of the HL as shown by the Scanning Electron Microscopy (SEM) test contributed to good interlocking of the aggregates in the mixtures. This was not observed in mixtures with OPC fillers which were of spherical particle shape. The X-Ray Diffraction (XRD) revealed that the HL particle has a higher capacity to diffract the X-rays, proving that it is a stronger material particle than the OPC. The Wheel Tracking test results showed that HL mixtures underwent less deformation than the OPC mixtures. A similar trend was observed in the Dynamic Creep Test. Based on the Beam Fatigue test, mixtures containing 4 % HL showed the best performance in fatigue amongst the other mixtures.

ABSTRAK

Terdapat banyak cara untuk meningkatkan prestasi campuran konkrit tar untuk mengurangkan kerosakan seperti perubahan bentuk kekal dan kelelahan struktur lebuh raya. Salah satu daripadanya yakni dengan menambahkan bahan pengisi. Bahan pengisi yang biasanya dikenali sebagai egen anti penanggalan adalah kapur terhidrat (HL) dan simen (OPC), di mana kedua-duanya memiliki komponen utama yang sama iaitu kapur (CaO). Kajian ini bertujuan untuk membandingkan sifat-sifat kejuruteraan campuran konkrit tar yang menggunakan kapur terhidrat (HL) dengan campuran yang menggunakan OPC sebagai galian pengisi untuk meningkatkan prestasi campuran tersebut. Sifat kejuruteraan dasar campuran-campuran tersebut ditentukan dengan "marshal mix design". Kandungan Tar Optimum kemudian ditentukan melalui beberapa ujian prestasi. Di antaranya termasuklah ujian perubahan bentuk kekal menggunakan Ujian "Dynamic Creep" dan Ujian "Wheel Tracking". Sedangkan sifat-sifat kelelahan campuran-campuran tersebut dianalisa menggunakan "beam fatigue test" (ujian kelelahan bendul). Temuan kajian ini menunjukkan bahawa bentuk zarah-zarah HL yang lebih kecil dan tidak beraturan, seperti yang ditunjukkan oleh Ujian "Scanning Electron Microscopy" (SEM) turut menyumbang dalam meningkatkan pengikatan diantara aggregat dalam campuran konkrit tar. Pencerapan ini pula tidak ditemui dalam campuran konkrit tar yang mengandungi OPC sebagai pengisi, yang menpunyai zarah-zarah yang berbentuk bujur-kebulatan. Ujian Pembelauan Sinar-X (XRD) pula menunjukkan bahawa zarah-zarah HL memiliki keupayaan pembelauan sinar-X yang lebih tinggi daripada OPC. Keputusan ini membuktikan bahawa zarah-zarah HL lebih kuat daripada zarah-zarah OPC. Dari hasil Ujian "Wheel Tracking" menunjukkan bahawa campuran konkrit tar mengandungi HL lebih tahan terhadap perubahan bentuk daripada campuran konkrit tar yang mengandung OPC. Hasil Ujian "Dynamic Creep" juga menunjukkan keputusan yang sama. Dalam Ujian Kelelahan pula, campuran konkrit tar yang mengandung 4% HL menunjukkan prestasi yang lebih baik berbanding dengan campuran yang lain itu.

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CHAPTER I

INTRODUCTION

1.1 Background

Most roads in Malaysia and other countries are surfaced with flexible pavement. Although rigid pavement has also been developed and has many advantages, the construction cost to build this pavement type is much higher than flexible pavement [1] [2]. Flexible pavements are constructed from bituminous and granular material. It consists of a large percentage of coarse and fine aggregates and a small percentage of bitumen and additive material. Although bitumen and additives make up a small percentage of the mixture; they play an important role in determining many aspects of the pavement performance.

One of the main functions of bitumen in flexible pavement is to act as an adhesive agent. The adhesion of bitumen to the aggregate is best achieved in the absence of water. The presence of water can lead to difficulties in maintaining an adequate bond between the binder and the stone in a phenomenon called “stripping” [3]. Several studies have revealed the advantages of using additives to prevent and solve this problem. Several types of additive materials have been used in pavement mixture such as fillers, fibers, antioxidants, thermoplastic polymers and chemical modifiers [2].

Mineral fillers are defined as fine material passing a 75 μm or No. 200 sieve size [4]. It has dual role in pavement mixtures. The portion of filler with thicker particles contributes to the interlocking of the aggregates. The rest of the portion of the filler are suspended in the bitumen and changes the physicochemical properties of the bitumen [5]. Several types of filler have been used in pavement construction; however, only a few that can be used as anti stripping agent such as Hydrated Lime and Ordinary Portland Cement [3], [6].

Hydrated Lime is produced from limestone ($CaCO_3$) or Dolomite ($CaCO_3$+$MgCO_3$) and when heated in a rotary kiln produce quicklime ($CaO+CO_2$ or $CaO+MgO+CO_2$). When water (H_2O) is added to the quicklime, a reaction occurs resulting in Hydrated lime (HL) [7]. Some researchers have found that the addition of HL as fillers in asphalt concrete mixture can control water sensitivity and act as an anti stripping agent [8] [9] [10] [11] [12]. Other work on the use of HL stated that their product can both reduce rutting and cracking due to fatigue [13] [9].

Another type of filler that can be used in bituminous mixtures is Ordinary Portland Cement (OPC). OPC is an artificial chemical product of fairly definite composition which contains 60 – 65 % lime, 20 – 25 % silica and 5 – 12 % iron oxide and alumina [7]. Some studies have stated that OPC makes good contribution to enhance the performance of Asphalt Concrete mixtures [3] [6]. The local authority in Malaysia stated that OPC can be added to asphalt concrete mixtures to serve as an adhesion and anti stripping agent [4].

It is believed that both fillers i.e. HL and OPC strongly adsorb the polar constituents of the bitumen to the negatively charged aggregate surfaces thereby giving improved adhesion [3]. Although both HL and OPC have the same major component in its content, i.e. lime, the behaviour of these materials in each asphalt concrete mixtures can show different results. Even if many researchers have observed the effect of both filler as anti-stripping agent in the asphalt concrete mixtures, the exact relationship of the specific filler property on the properties and performance of the bituminous mixture has not been defined clearly, particularly in terms of the role of both fillers in arresting pavement deterioration such as permanent deformation and fatigue cracking. More studies are needed to compare the role of these fillers to address pavement distress. This study is undertaken in order to compare both fillers properties namely the physical and chemical properties and their composition and relate them to the performance of the resulting asphaltic concrete mixtures.

1.2 Objectives

The main objective of this research is to compare the performance of Hydrated Lime (HL) and Ordinary Portland Cement (OPC) as Filler in Asphalt Concrete mixtures.

1.3 Scope of study

The scope of this study comprises the following:

1. Using local material as coarse and fine aggregates.
2. To determine the physical and chemical properties of the filler studied namely HL and OPC
3. To use the Marshall Mix Design in obtaining the optimum bitumen content and the engineering properties of the resulting bituminous mixtures.
4. To conduct performance tests on the AC bituminous mixtures using 3 types of tests; namely a Wheel Tracking Test (Rutting Test), Dynamic Creep Test, and Beam Fatigue Test. The first two tests look into the deformation characteristics of the mix whilst the last test addresses the fatigue properties of the mix.

1.4 Thesis Outline

This thesis consists of five (5) chapters; namely introduction, literature review, methodology, results and discussion and conclusions and recommendations. A whole range of systematic experimental works have been performed to meet the objective of this study using standard tests. This standard tests conform to the British Standards, ASTM (American Standard Testing of Material) standards and the Malaysian Standard for Public Works.

Chapter 1 consists of the background of this study, objectives, scope of study and thesis outline.

Chapter 2 is a literature review of the study and addresses the role of filler in bituminous mixtures. Reference is also drawn from many studies on filler behavior. Types of pavement distresses together with the benefit of filler addition are also described in this chapter.

Chapter 3 describes the material properties used and the steps of experimental work employed in this study. The methods as well as specific testing procedures conducted in this study are also highlighted

Chapter 4 presents the results and discussion of the analyses conducted in this study. This include the properties of filler, mixtures engineering properties (i.e. density, voids in mineral aggregate (VMA), voids filled with bitumen (VFB), air voids, stability, flow, and stiffness) and also performance tests on permanent deformation and fatigue characteristic.

Chapter 5 presents the conclusions of this study based on the results, discussion made and recommendations for further study.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

Deterioration in highway pavement is caused by several factors. The common factors usually are related to traffic loading and environmental factors. Many studies have been carried out by researchers to address pavement deterioration. One of recommendations is by adding additive material into the bituminous mixture. Additive material such as mineral filler, fiber, polymer, adhesion improvers, etc are believed to be able to enhance pavement mixture performance. The application of additives in pavement mixture must meet certain criteria. Beside performance, other criteria included are ease of availability, practically of usage and economic considerations which must be considered before adopting a particular additive.

Additions of mineral fillers have been commonly used as an economical method in pavement mixtures. Kallas and Puzinauskas spelled out the advantages of using mineral fillers. Fillers play dual functions in pavement mixtures. Besides changing the properties of bitumen by being suspended inside the bitumen, it can also contribute in enhancing the contact point between the aggregates inside the mixtures [5]. Heukelom stated that the addition of mineral filler into bituminous mixture can increase the workability of the mixture, this behavior influencing the compactibility and spreadability of the bituminous mixture during construction [14]. Until now, many studies were conducted to reveal the advantages the use of mineral filler in bituminous mixtures. Maupin did field investigation in comparing pavement performance using chemical additives and some type of mineral fillers. He investigated nine pavements which have been constructed during 1991 – 1992 in Virginia district by taking 10 core drill samples of each pavement for stripping test and 10 core drill samples for void determination. The study showed that the pavement performance using chemical additive didn't show better performance than the pavement which used some type of mineral filler [15].

2.2 Mineral Filler

Mineral fillers have been used in asphalt mixtures to fill the voids between the larger aggregate particles. In generally, filler can be considered as the fine material which is not less than 70% by weight passing the 75 µm or No.200 sieve [4] such as rock dust, slag dust, hydrated lime, hydraulic binder, fly ash, etc.

Kallas and Puzinauskas have stated that mineral filler has dual role in the paving mixture. It can be suspended in the bitumen that changing the properties of the binder films. On the other hand, if the aggregate in the mixture is well-graded and the mixture contains small quantities of bitumen, a part of filler will contribute in contact point between aggregate inside the mixtures [5].

Another study by Puzinauskas has mentioned that because of their size, fillers can increase the contact points between the aggregates and bitumen that give contribution in increasing the stability of bituminous mixture [16]. It is believed also that addition of mineral filler in the asphaltic concrete mixtures can improve mixtures workability and also can change the type, grading and bulk density of the mixtures [2].

Heukelom also stated that filler type and filler quantity have significant effect in workability of mixture [14]. It is believed that workability is measurement of two different properties namely spread ability and compactibility. It was stated also in previous study that the physical properties of filler i.e. particle size distributions is the fundamental filler parameters that affect the void content and average void diameter of packed powders [17].

Other researchers have found that the function of fillers in bituminous mixtures is not only as a void filler but also contribute to the physical-chemical reaction in the asphaltic concrete mixtures [18]. Other study noted that the mixture consistency is controlled by the volume filling and physic-chemical reinforcing nature of the filler rather than by mineral to mineral contact [19]. Filler can also increase the stability of asphaltic concrete mixtures by increasing the viscosity of binder [20]. It means that softer bitumen can be made into harder grade by adding filler.

Rigden classified the principal characteristics of filler based on their primary characteristic and secondary characteristics. Primary characteristics consist of particle density, particle shape, particle surface texture, particle size distribution and surface area. Meanwhile, bulk density, fractional voids, and pore diameter were categorized as secondary characteristic [20].

The filler geometric irregularity can be evaluated either by microscopic inspection or particle dimensional analysis [21]. The geometric irregularity is a property which expresses a combination of shape, angularity, surface texture and open porosity. All these are related to the specific surface of the filler particle.

Bolk et.al also stated that mineral fillers addition can enhance the resistance of asphaltic concrete mixtures from permanent deformation [22]. Another work stated that stability in the bituminous mixtures is mainly affected by the resistance of particle movement caused by the interlocking of aggregates and filler packing [23].

According to a previous study, the maximum amount of filler that could be added in bituminous mixture is around 20% of the total weight [24]. Amount in excess of 20% are prone to produce cracks in bituminous mixtures when rolled. They are also discovered in their study that in warm weather i.e. in excess of 40^{o}C, the pavement with excessive filler amount exhibited more cracking under traffic loads. Eick and Shook stated that higher percentage of filler requires higher compaction temperature. The higher percentage of filler content increase the bitumen viscosity, this affect the compaction temperatures because of bituminous mixtures become tougher to compact. Higher temperature is needed to reduce the bitumen viscosity. [25].

Previous studies have mentioned several types of mineral filler used in asphaltic concrete mixtures as an anti stripping agent [16] [26]. Notable amongst these are Hydrated Lime (HL) and Ordinary Portland Cement (OPC) [3] [6] [12].

Anti-stripping agent is an additive usually added to bituminous mixture to overcome the problems associated to loose of adhesion between the bitumen and the aggregate surface. The adhesion of bitumen to aggregate surface is enhanced in the absence of water. The presence of water can lead to difficulties in maintaining an adequate bond between the binder and stone in the presence of water known as “stripping” [3] [7]. The main objective of adding these additives was to enhance adhesion (Retain from stripping) in bituminous mixtures that uses hydrophilic (water loving) aggregate [27].

Several studies on the effect of these anti stripping agents have revealed the effect of hydrated lime and ordinary Portland cement fillers in asphaltic concrete mixtures. There are several anti-stripping additive types such as iron napthenate, cationic surfactant, oregano saline, hydrated lime and ordinary Portland cement. However, based on the previous field investigation has been done by Maupin, pavement performance which used chemical additive didn't show better performance than pavement which used hydrated lime or ordinary Portland cement [15].

One recent study has stated that both lime and Portland cement when used as fillers can increase the Marshall Stability, resilient modulus, tensile strength, resistance to moisture damage and resistance to permanent deformation in cold-in-place recycling (CIR) mixes [10]. Other work has revealed that hydrated lime addition increased the resistance of asphalt mixtures to the detrimental effect of water [28].

Some researchers have also stated that the application of recycled waste lime as mineral filler improves the permanent deformation characteristics, stiffness and fatigue endurance of asphalt concrete at the wide range of temperatures [8]. It was also determined that the mixtures with recycled waste lime showed higher resistance against stripping than conventional asphalt concrete.

2.3 Ordinary Portland Cement (OPC)

Ordinary Portland cement (OPC) is a hydraulic material which shall consist of at least two-thirds by mass of calcium silicates ($3CaO.SiO_2$ and $2CaO.SiO_2$), the remainder consisting of aluminium- and iron-containing clinker phases and other compounds [29]. OPC is made by heating a homogeneous mixture of raw materials in a kiln to a sintering temperature, which is in the range of 1400-1600°C [7]. The major raw material for the clinker-making is usually limestone ($CaCO_3$) mixed with a second material containing clay as a source of alumina-silicate.

Because of its fineness, OPC can be used as mineral filler in flexible pavement to fill the void resulting in a viscous mastic system. As stated in the JKR standards [4], the OPC shall be added to asphalt concrete mixtures to serve as an adhesion and anti stripping agent [4]. It was also stated by another researcher that asphaltic concrete mixtures incorporating OPC is found to be more resistant in terms of stripping [30].

A previous study has revealed that an incorporation of OPC into bitumen was found to result in a lower consistency binder reflected by higher penetration; lower softening point temperature and viscosity compared to the fillers such as hydrated lime, fly ash, limestone and silt [31]. In addition the use of OPC as filler in bituminous mixtures can increase the engineering properties of the mix such as Marshall Stability, resilient modulus, tensile strength, resistance to moisture damage and resistance to permanent deformation of cold in place recycling (CIR) mixes [10].

Accordance to the previous research, mixtures containing OPC has higher density than mixtures containing HL [5]. It is expected can enhance the Marshall Stability result in pavement mixture. Investigation have been done by Richardson stated that silica, limestone dust and Portland cement made better fillers as they adsorbed a correspondingly thicker film of bitumen [18].

Guirgus et al investigated the use of cement-coated aggregate mixtures to improve the pavement performance. The result showed that the resistance of cement-coated aggregate mixtures to the action of water is as high as those treated with hydrated lime, and the retained strength after immersion in hot water is almost 100% [32]. Another study reported that the addition of 1% of Portland cement can increase stability by 250-300% over that of untreated hot-mix asphalt. Flexural fatigue resistance was also increased when cement treated aggregate mixtures were used [33].

Another finding by Warden, Hudson, and Howell stated that comparison of OPC and HL as bitumen filler in penetration test has shown that bitumen containing OPC has flatter slope graph than bitumen containing HL. This slope measured the relative effectiveness of filler in decreasing penetration value resulting stiffer mixture [26]. This research also conducted an experiment on the effect of both filler in bituminous mixture using Marshall Stability test. The result categorized OPC as a 1st class filler and HL as a 2nd class filler. It means that mixtures containing OPC in binder has better performance than mixtures containing HL. Even Marshall Test has been widely used; it still has limitations to measure of resistance to permanent deformation [34]

2.4 Hydrated Lime (HL)

Hydrated Lime is a chemical compound with the chemical formula $Ca(OH)_2$ that can be obtained from limestone ($CaCO_3$) or Dolomite ($CaCO_3$+$MgCO_3$) which heated in rotary kiln to produce quicklime ($CaO+CO_2$ or $CaO+MgO+CO_2$), then when water (H_2O) is added to quicklime, a reaction takes place resulting Hydrated lime [7].

The normal grades of hydrated lime have 75% to 95% passing the No.200 sieve. The range of specific gravities and bulk-specific gravities for different hydrates are 2.3 to 2.9 and 400 to 640 kg/m3, respectively. The use of 1-3% hydrated lime as filler content has been traditionally used to prevent stripping in bituminous mixture [2].

Hydrated lime has been known as a potential and multifunctional modifier in asphalt. It improves the rheological properties of asphalt binders as inert filler that will impart in stiffening of the asphalt mixture and enhancing in resistance to permanent deformation [35]. It is proofed also by Rajagopal et al., the result showed that the addition of hydrated lime in bitumen gave stiffening effect when tested using Torsional Rheometer machine [36].

Hydrated lime also has an active filler effect that gives a unique ability to reduce age hardening characteristics of asphalt mixtures by interacting with reactive polar compounds in the binder, hence, reducing the carboxyl-type oxidation products formed during aging and reducing the ratio of asphaltenes to oxidation products formed upon oxidation [2] [11].

Hydrated Lime is also well known as active filler that can change the physical properties of a mix through its chemical interaction with the bitumen. Previous studies have reported that hydrated lime ties up carboxylic acids and 2-quinolones in the bitumen with the formation of insoluble calcium organic salts; this process prevents these functionalities from reacting with a siliceous surface to form water-sensitive bonds. This phenomenon leaves important active sites on the siliceous surface to form strong water-resistant bonds with nitrogen groups in the bitumen Mixture Design [9] [11] [10] [12] .

It has been proposed also by Ishai and Craus that the lime and water solution containing calcium ions result that causes the basis of aggregate surface. Water was forced away from the aggregate and asphalt emulsion with electro-chemical balance and then form a hydrophobic surface in the aggregate [37]. Other studies that compare the performance of hydrated lime, limestone and glass beads have stated that hydrated lime has the highest surface and geometric irregularity among other activities. It is believed would change the physical-chemical properties of asphalt mixture [37].

There are several addition techniques of hydrated lime into asphaltic concrete mixtures. Button et al. introduced that hydrated lime can be added in three (3) ways i.e. (1) Adding dry hydrated lime into dry aggregate, (2) adding dry hydrated lime into wet aggregate, (3) adding hydrated lime in the form of slurry [38].

Previous research has indicated that the amount of hydrated lime needed to improve the moisture sensitivity of hot mix asphalt is 1–2% by dry weight of aggregate [39]. Even though there are several types of anti-stripping agent, the hydrated lime appeared to perform better than liquid anti-striping agents [15] [40].

2.5 Types of Pavement Distress

There are different forms of distresses in asphalt pavements. The distresses can be caused by deficiencies in design, construction, material, maintenance or combination thereof. Knowledge of the various types of distress is important, because it can help to identify the causes of the distress. There are two main performance criteria in pavement design i.e. permanent deformation (rutting) and cracking [2]. Based on"a guide to the visual assessment of flexible pavement surface conditions" [41], rutting and cracking are defined in the following sections.

2.5.1 **Rutting**

Rutting is the result of repeated loading, which causes an accumulation and increase of permanent deformation. A rut can be defined as a longitudinal depression in the wheel path, with or without transverse displacement. It can be measured using a straight edge or a profiler at regular intervals [41]. A rut depth of 0.5 inch is considered a rutting failure generally. In a wet weather, it can be filled by water and can result in vehicles aqua planning. Thus, a deformed pavement presents a safety hazard and this can be categorized as a failure.

Consolidation in pavement by traffic can happen after construction. The traffic provides a repeated kneading action in the wheel track areas and completes the consolidation to the designed air voids. When compaction is poor, a substantial amount of rutting can occur. Rutting also results from lateral plastic flow (permanent deformation) of the HMA from the wheel tracks. Utilization of excessive asphalt cement is the most common cause for this phenomenon. It causes the loss of internal friction between aggregate particles. Plastic flow can be minimized by using angular and rough-textured aggregate and providing adequate compaction at the time of construction [42].

The bitumen viscosity also plays important role in the rut resistance of HMA. Some increased resistance to rutting can be obtained by using stiffer asphalt cements [20]. Thus, it makes the mix more resistant to rutting. However, use of excessive fines particles should be avoided. Accordance to previous study, the maximum amount of fines particle that could be added in bituminous mixture is around 20% from total weight [24]. Excess amount from 20% produce crack in bituminous mixtures while being rolled

Several researches have revealed the method to overcome rutting. One reference stated that based on testing using pneumatic-tyred wheel tracking machine at 30^{o}C, the addition 3% of filler reduced deformation about 40% in properly compacted mixtures [2].

Types of filler such as OPC and HL are usually used to reduce rutting. Previous study stated that hydrated lime besides is used to improve the mechanical quality of soils, it is also significantly improves the performance of asphalt. Unlike most mineral fillers, lime is chemically active rather than inert. It reacts with the bitumen, removing undesirable components at the same time go that its tiny particles disperse throughout the mix, thus making it more resistant to rutting and fatigue cracking [43]. It has also an excellent performance in water damage and resistance to permanent deformation [44].

Niazi et al. have investigated the effect of OPC, HL slurry and hydrated lime in permanent deformation. The results of wheel track test showed that the samples without additives have the most rutting. The addition of 2% Portland cement, 2% HLS and 2% HL resulted in a reduction in rut depth of 58%, 50% and 38% as compared to samples without additives, respectively. Both tests show that addition of Portland cement and lime can reduce the permanent deformation of recycled mixtures [10].

2.5.2 **Cracking**

Cracks are fissures resulting from partial or complete fractures of the pavement structures [41]. It can happen in a wide variety of patterns. Pavement cracks generally can be categorized in 3 type's namely longitudinal crack, transverse crack, and block crack. Several possible matters can cause this problem such as depression, exceeding of surface fatigue life, surface age embrittlement, shrinkage, poor construction joint, etc. Commonly, cracking happens in stiffer asphaltic concrete mixtures to trigger micro cracks. It occurs when the tensile stress and related strain induced by traffic and temperature change exceed the breaking strength of mixture [2]. Shell Bitumen mentioned several types of cracking usually occur in pavement.

Fatigue cracking

This type of cracking is usually associated with load, which is fracture under repeated or fluctuating stress having a maximum value less than the tensile strength of the material. This type of cracks will occur depending on the fatigue properties of the pavement. It can be caused by a single excessive load, slippage, lateral movements in fills due to traffic, and excessive strains associated with rutting. Fatigue cracking can be minimized by controlling several variables, such as aggregate gradation, asphalt content with rough textured aggregate, air voids, and water content [2].

Low temperature cracking

This type of cracking is usually happened in asphalt pavements constructed in cold weather climates. As the temperature drops, the restrained pavement tends to shrink. The tensile stresses build up to a critical point when a crack is formed and partial stress relief occurs. These cracks can be initiated by traffic, cycles of temperature changes, and then propagated by a large drop in temperature. The most significant effects on crack formation and propagation are aging and moisture.

Reflection cracking

Reflection cracking can be described as the surface replication of the joints and cracks that are located in the underlying layers of the pavement and foundation materials. Reflection cracking includes the cracking of a surface course of the original pavement due to the reflection of a joint or crack originating in a base course or subgrade as well as cracking of an overlay.

Many ways to prevent the cracking, one of them is by changing the bitumen properties. Addition mineral filler is the one alternative way to change the bitumen properties [18]. Filler addition can reduce the mixtures void. It can also increase the relative volume of the bitumen, thereby increasing the fatigue performance because the strain produced is smaller.

One study has revealed that the addition of lime makes it possible to improve fatigue characteristics and reduce cracking [35]. This is caused by 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. Another study on the effect of OPC in mixtures reported that the addition of 1% of Portland cement can increase stability by 250-300% over that of untreated hot-mix asphalt. Flexural fatigue resistance was also increased when cement treated aggregate mixtures were used [33].

2.6 Summary

Many literatures have stated that HL and OPC have own advantages. Some researchers have stated that HL has good performance in stripping, while the others stated that OPC showed good performance in resistance from rutting in bituminous mixtures. Although both filler have same dominant oxide, but when it is being added into bituminous mixtures, it will give different effect. Some researchers showed contradictive results among other. Most of them also applied the utilization these filler to asphaltic concrete mixtures in low percentage filler content, which is in the ranges of 1-3% of filler content. This study has purpose to reveal the comparative analysis between HL and OPC in the same bituminous mixtures condition at the wide ranges percentage filler content as stated by JKR, which are 2-8 % filler content. This study also summarized the performance of both filler in performance test and ranked apple to apple based on several performance tests result. The summary of the previous study of the HL and OPC as filler in the bituminous mixture is presented in the Table 2.1.

Table 2.1 Summary of Literature Review

Result from previous studies	Type of filler	
	HL	OPC
Comparison with other additive	Pavement performance which used chemical additive didn't show better performance than pavement which used hydrated lime or ordinary portland cement (Maupin, 1997)	
Filler effect into bituminous mixtures	- HL addition increased the resistance of asphalt mixtures to the detrimental effect of water (Sengoz and Gorkem, 2009), - Recycled waste lime as mineral filler improves the permanent deformation characteristics, stiffness and fatigue endurance of asphalt concrete at the wide range of temperatures (Mun, Keun and Do, 2007). - The use of 1-3% hydrated lime as filler content has been traditionally used to prevent stripping in bituminous mixture (Shell Bitumen, 2003) - Hydrated lime improves the rheological properties of asphalt binders as inert filler that will impart in stiffening of the asphalt mixture and enhancing in resistance to permanent deformation (Little and Lesuerr,1999) - Hydrated lime has an active filler effect that gives a unique ability to reduce age hardening characteristics of asphalt mixtures by interacting with reactive polar compounds in the binder, hence, reducing the carboxyl-type oxidation products formed during aging and reducing the ratio of asphaltenes to oxidation products formed upon oxidation (Petersen, 2005). - The hydrated lime appeared to perform better than liquid anti-striping agents (Abo Qudais, 2007) - Hydrated lime besides is used to improve the mechanical quality of soils, it	- OPC when used as fillers can increase the Marshall Stability, resilient modulus, tensile strength, resistance to moisture damage and resistance to permanent deformation in cold-in-place recycling (CIR) mixes (Niazi and Jalili, 2008) -Asphaltic concrete mixtures incorporating OPC is found to be more resistant in terms of stripping (Mehta, 1978) - Guirgus et al (1982) investigated the use of cement-coated aggregate mixtures to improve the pavement performance. The result showed that the resistance of cement-coated aggregate mixtures to the action of water is as high as those treated with hydrated lime, and the retained strength after immersion in hot water is almost 100% - Warden, Hudson, and Howell (1959) stated that comparison of OPC and HL as bitumen filler in penetration test has shown that bitumen containing OPC has flatter slope graph than bitumen containing HL - The addition of 2% Portland cement, 2% HLS and 2% HL resulted in a reduction in rut depth of 58%, 50% and 38% as compared to samples without additives, respectively. (Niazi et al. 2008)

	is also significantly improves the performance of asphalt. Unlike most mineral fillers, lime is chemically active rather than inert. It reacts with the bitumen, removing undesirable components at the same time go that its tiny particles disperse throughout the mix, thus making it more resistant to rutting and fatigue cracking (Plancher, Harnsberger and Petersen, 1987) - It has also an excellent performance in water damage and resistance to permanent deformation (Ping and Kennedy, 1991)	
Primary content and The process of making the filler	Hydrated Lime is a chemical compound with the chemical formula $Ca(OH)_2$ that can be obtained from limestone ($CaCO_3$) or Dolomite ($CaCO_3$+$MgCO_3$) which heated in rotary kiln to produce quicklime (CaO+CO_2 or CaO+MgO+CO_2), then when water (H_2O) is added to quicklime, a reaction takes place resulting Hydrated lime (Eckel, 2005)	OPC is a hydraulic material which shall consist of at least two-thirds by mass of calcium silicates ($3CaO.SiO_2$ and $2CaO.SiO_2$), the remainder consisting of aluminium- and iron-containing clinker phases and other compounds. The major raw material for the clinker-making is usually limestone ($CaCO_3$) mixed with a second material containing clay as a source of alumina-silicate. (ASTM C-150/150M-09). OPC is made by heating a homogeneous mixture of raw materials in a kiln to a sintering temperature, which is in the range of 1400-1600°C (Eckel, 2005)
Effect on mixtures consistency	-OPC into bitumen was found to result in a lower consistency binder reflected by higher penetration; lower softening point temperature and viscosity compared to the fillers such as hydrated lime, fly ash, limestone and silt (Sayed, 1988) -The addition of hydrated lime in bitumen gave stiffening effect when tested using Torsional Rheometer machine (Rajagopal, 2007).	
Effect on Density	Accordance to the previous research, mixtures containing OPC has higher density than mixtures containing HL. It is expected can enhance the Marshall Stability result in	

	pavement mixture (Kallas and Puzinauskas, 1961)	
Filler content	The amount of hydrated lime needed to improve the moisture sensitivity of hot mix asphalt is 1–2% by dry weight of aggregate (Jones, 1997)	The addition of 1% of Portland cement can increase stability by 250-300% over that of untreated hot-mix asphalt. Flexural fatigue resistance was also increased when cement treated aggregate mixtures were used (Eriksen, 1993).
	Based on testing using pneumatic-tyred wheel tracking machine at 30^{o}C, the addition 3% of filler reduced deformation about 40% in properly compacted mixtures (Shell bitumen, 2003)	

CHAPTER III

MATERIALS USED AND TEST IN THE STUDY

3.1 Introduction

This chapter describes in detail the general scheme of this study. It starts with materials preparation followed by mixture preparation, performance tests and mixtures optimization. Material selection and characterization of materials properties were included in material preparation. Materials used in this research were selected according to the specifications that matched with the objectives of this research and met the requirements of the appropriate British Standards (BS), American Society for Testing and Materials (ASTM) or Jabatan Kerja Raya (JKR) standards.

The properties of the bituminous mixtures were determined using the Marshall test which enables the determination of the optimum bitumen content (OBC) by optimizing several parameters of the mixture properties i.e. Stability, Air Voids, Voids in Mineral Aggregate (VMA), and Stiffness. The results of the OBC then were used to fabricate samples and conduct performance test on the bituminous mixtures.

The performance tests conducted in this study involve the fatigue characterization and permanent deformation of the mix. Fatigue characteristics were determined by using the beam fatigue test; whereas permanent deformation was analyzed by using two different tests i.e. wheel tracking test and the dynamic creep test. The best mix was then determined based not only on the OBC, but also on the optimization of the performance tests namely that which addresses issues of fatigue failure and permanent deformation. The flowchart of this study is shown in Figure 3.1.

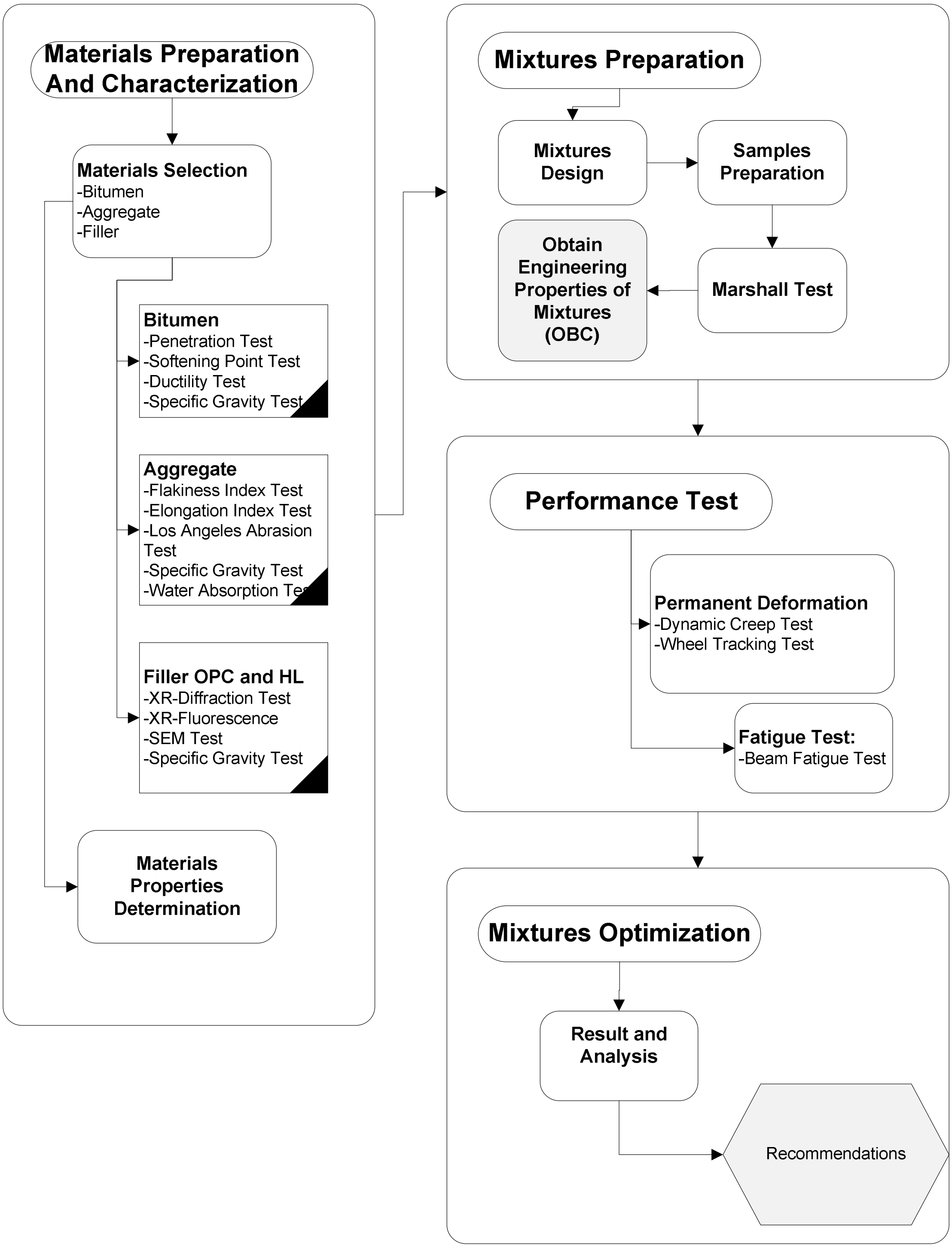

Figure 3.1 .Research Flowchart

3.2 Materials Preparation

Materials used in this research were selected according to the specifications meeting objectives of this research and the requirements of the appropriate British Standards, ASTM and JKR Standards. The details of the material preparation are presented as follows.

3.3 Materials Selection

The selections of material and mixture design were referred to the JKR standards [4]. In this study, asphaltic concrete (AC) mixture designated as ACW 20 was used. This gradation is adopted by JKR for asphaltic concrete mixtures used for the wearing course with a maximum aggregate size of 20 mm. Asphaltic concrete is a continuously graded mixture of mineral aggregate, filler, and bituminous binder which form an interlocking structure within the mix [3]. This interlocking aggregate structure is the major contributor to the strength and performance of the laid material. The percentage of bituminous binder is relatively low. The binder acts as an agent to glue the aggregates inside the mixture. An asphaltic concrete mixture is also designed to produce materials with minimum voids. The combination of minimum voids and good interlocking will result in asphaltic concrete mixtures that have good resistance to permanent deformation [3] [45].

There are different types of asphalt concrete mixtures gradation. Every country and standard has their own specification of the aggregate gradation specification. It includes the percentage range of aggregate sizes and the suggested ranges of bitumen content. The maximum aggregate size used in this study was that retained on size 20 mm British Standard (B.S) sieve. The aggregate were sieved to ensure that the aggregate used in the mixtures conforms to the standard. The bitumen content ranged from 4.5% to 6.5%. The specification can be shown in Table 3.1

Table 3.1 JKR Gradation Limits (ACW 20)

Mix Type	Wearing course
Mix Designation	ACW 20
B.S. Sieve	% Passing by Weight
28.0 mm	100
20.0 mm	76-100
14.0 mm	64-100
10.0 mm	56-81
5.0 mm	46-71
3.35 mm	32-58
1.18 mm	20-42
425 um	12-28
150 um	6-16
75 um	4-8
Bitumen Content	4.5 – 6.5 %

3.4 Bitumen

Bitumen can be considered as a viscous liquid or a solid, consisting essentially of hydrocarbons and their derivatives, which is soluble in trichloroethylene and is substantially nonvolatile and softens gradually when heated [46]. Bitumen has an important role in asphaltic concrete mixtures. It acts as a binding agent to the aggregate material. The types of bitumen use in bituminous mixtures have an influence on the compactibility of the resulting mixes. The softer bitumen achieves better compaction than the harder bitumen when the same filler type and compaction effort are used [2] [47].

Bitumen is obtained from the petroleum refinery processes. It is black or brown in color and has adhesive and waterproofing properties. Nevertheless, presently the most commonly used binder for highway construction is petroleum bitumen.

Bitumen has varying chemical compounds that form its properties, namely asphaltenes, resins, aromatics, and saturates. Proportion of chemical inside bitumen may influence the performance of bitumen in the mixture. Asphaltenes are brown/black amorphous solids which comprise 5-25% by weight of bitumen [2]. Harder bitumen has a higher asphaltenes from the same crude oil. Furthermore bitumen can be categorized as a viscous-elastic material. It behaves as a viscous liquid at high temperatures or long times of loading. At the intermediate range of temperature and loading times, typical of conditions in service, bitumen behaves in a viscous-elastic manner, whereas at very low temperature or short times of loading they behave as elastic (brittle) solids. Higher bitumen stiffness will increase mixtures stiffness [2]. Thus, its deformation under stress is a function of both temperature and loading time. Another research also stated that the reinforcement of asphaltic concrete is dependent on time of test, nature of the bitumen and type and size of material [19].

Based on the previous study [48], the asphalt-mineral filler mastics show an increased tensile strength and tensile failure strain with the addition of mineral fillers; these findings are valid for limited mastic systems, and the moisture effects were not considered. Nonetheless, the effects of active filler through its chemical interaction with an asphalt-aggregate system can compensate for the adverse effects of inert filler.

Bitumen used in this study was taken from Petroliam Nasional Berhad (PETRONAS) which had a penetration in the range of 80 / 100. Typical tests have been held to bitumen were Penetration Test, Softening Point Test, Ductility test and Specific Gravity test. The bitumen was heated to approximately 160^{o}C before it was mixed with the aggregate and filler.

3.4.1 **Penetration Test**

Penetration test refers to BS 2000: Part 49: 1983 and ASTM Test D5 [49]. The equipment needed in this test is a Penetrometer with a needle which bears a load of about 100 gram. The needle was set to the surface of the material and allowed to penetrate the bitumen sample which was maintained at a temperature of 25^{o} C in 5 seconds. The distance penetrated by the needle into the sample of bitumen is termed the Penetration. It is measured in units of tenth of a millimeter (dmm). The objective of this test is to measure the consistency of a penetration or oxidised bitumen. This test gives an empirical measurement of the consistency of the material tested in terms of the distance a standard needle sinks into that material under prescribed loading and time. The penetrometer apparatus and illustration of the penetration test are shown in Figure 3.2 and Figure 3.3. Two samples were prepared for each mixture variation and 3 set of tests were conducted for each sample. The penetration value should lie within a specified range. The penetration test result is shown in Table 3.2

Figure 3.2 Penetrometer device

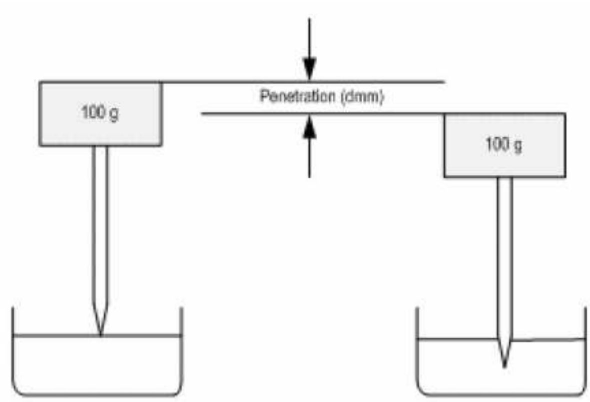

Figure 3.3 Penetration test ilustration

3.4.2 Softening Point Test

The purpose of this test is to measure the susceptibility of bitumen to temperature changes by determining the temperature at which the material will adequately softened to allow a standard ball to sink through it. The reported temperature is designated the softening point of the bitumen and represents an equi-viscous temperature of the bitumen. The test was conducted accordance to BS2000: Part 58:1983 and ASTM D5 [50] which specified the methods used to conduct this test. To find the softening point value, 3.5-gram steel balls was placed on the surface of the bitumen specimen that has been placed into tapered brass rings. The set up was placed in water where the temperature was increased at a rate of 5^{o} C/min steadily until the bitumen will then soften. The ball stretches the bitumen and forces the underside of the bitumen to fall 25 mm onto a base plate. The softening point temperature is obtained when the bitumen touches the plate. The softening point apparatus and the illustration of softening point test are shown in Figure 3.4 and Figure 3.5. The result is shown in Table 3.2.

Figure 3.4 Softening Point test device

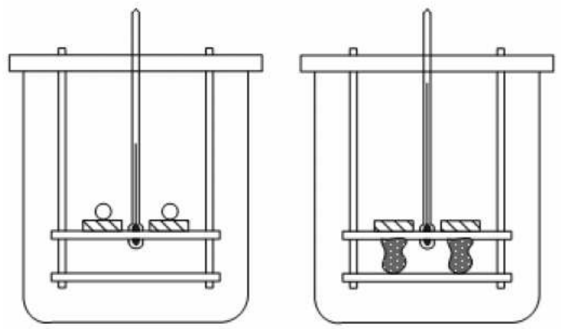

Figure 3.5 Softening Point Test illustration

The test is performed in duplicate and the mean of the two measured temperatures is reported. If the difference between the values obtained in the duplicate determination exceeds 1^{o}C, the test is repeated.

3.4.3 Ductility Test

The Ductility test aims to measure the cohesiveness of the bitumen material. Although the exact value of ductility is not as important as the existence or non existence of the property in the material, this is an important characteristic for bitumen. This test is described fully in AASHTO Designation T51 and ASTM D113 [51]. To start this test, the bitumen was heated and then poured it into a standard mould to form a briquette of at least 1 cm^2 in cross sectional area. The material is the allowed to cool at 25^{o} C (room temperature) in water bath. The prepared sample is then placed into the ductility machine as shown in Figure 3.6. Two dump-bells of bitumen were stretched at a constant speed of 50 mm per minute until fracture occurs. The distance the specimen stretched before failure was reported as the ductility value. The illustration of ductility test is shown in Figure 3.7.

Figure 3.6 Ductilometer

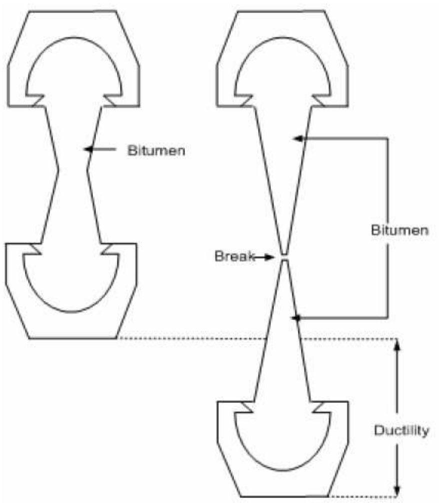

Figure 3.7 Ductility test illustration

The prepared sample is then placed into the ductility machine as shown in Figure 3.6. Two dump-bells of bitumen were stretched at a constant speed of 50 mm per minute until fracture occurs. The distance the specimen stretched before failure was reported as the ductility value. The illustration of ductility test is shown in Figure 3.7.

3.4.4 **Bitumen Density**

Then 25 ml pycnometer has been used to measure the bitumen density. This test is used to measure the specific gravity of bitumen. ASTM Designation D70-03 [52] specifies methods to conduct this test. The sample is placed in a calibrated pycnometer and then the pycnometer and the sample are weighed. Next, the filled pycnometer is brought to the test temperature, and weighed. Afterwards, the density of the sample is calculated from its mass and the mass of water displaced by sample in the filled pycnometer. The 25 ml pycnometer is shown in Figure 3.8.

Figure 3.8 the 25 ml ultrapycnometer

Table 3.2 The Bitumen 80/100 Properties

No	Property	Average Value Obtained from Laboratory Test
1	Penetration Test (dmm)	89.3
2	Softening Point Test (^{o}C)	50.5
3	Ductility Test (cm)	129.5
4	Specific Gravity Test	1.039

3.5 Aggregate

As an important component in the asphaltic concrete mixtures, the aggregate has a function to provide stability to the asphaltic mixtures to make a good interlocking inside the mixtures. It can be obtained by ensuring good gradation and frictional resistance to creep. A previous study has shown that dense graded aggregate mixtures can produce better stiff mixture than the open or gap graded material [53]. Thus, it is necessary to consider the certain properties of aggregate to meet the requirement of the specification.

An aggregate was divided into two types, coarse aggregate and fine aggregate. Coarse aggregate is classified as material that has a size greater than 3.35 mm sieve size, while fine aggregate is categorized as a material that has a particle size within the range of 75 um - 3.35 mm [54]. In a research about stripping, aggregate surfaces rich in metallic elements such as calcium can enhance the stripping resistance [55]. This resistance to stripping is due to the fact that such metals strongly associate with bitumen acids and thus, forming hydrophobic salts which are not water soluble. It was mentioned also in one literature that the vast majority of aggregates are classified as hydrophilic (water loving) or oleo phobic (oil hating) [2]. Aggregate with a high silicon oxide content such as quartz and granite are commonly more difficult coated by bitumen than basic rocks such as limestone and basalt.

The studies were conducted by previous researcher [55] found that some of the aggregate physical properties possible to influence moisture damage included surface roughness, porosity, shape, friability and the presence and nature of adsorbed coatings. Good bonding is promoted by rough-textured aggregate surfaces. Other researchers have also stated that the properties of the bituminous mixtures can be influenced by aggregate particle shape and size [56] [57].

Two types of aggregate materials were used in this study. Granite crushed rock for coarse aggregate and river sand for fine aggregate. Coarse aggregate was categorized as the aggregates that were retained on 5 mm B.S sieve, while those that passed the sieve size were classified as fine aggregate.

The range of JKR gradation specification and aggregate gradations used in this study are shown in Table 3.3. Both coarse and fine aggregates were sieved by using the sieve shaker. The aggregates were then washed and dried in the oven for ± 24 hours. They were put in the containers and classified based on their particle size. Each aggregate particle size was weighed based on the aggregate gradation proportion in every mixture in order to meet the aggregate gradation requirements in all the bituminous mixture specimens. The aggregate passing of 75 μm sieve size was arranged in the value between 2 – 8 % with the increment of 2%. Then the aggregate passing of 150 µm sieve size will adjusted suitable with the value of aggregate passing on 75 µm sieve size. The total percentage of aggregate weight must reach 100%. Thus, there is no aggregate gradation variation in this study except the filler content. The gradation curve is shown in Figure 3.9.

Table 3.3 .Aggregate Gradation (JKR Standards: 1988)

	Specification	**Gradation Used**	**Weight Retained (gram)**	**Weight Passing (gram)**
BS Sieve	**% Passing by weight**			
28.0 mm	100	100	0	1200
20.0 mm	76-100	88	144	1056
14.0 mm	64-100	82	72	984
10.0 mm	56-81	68.5	162	822
5.0 mm	46-71	58.5	120	702
3.35 mm	32-58	45	162	540
1.18 mm	20-42	31	168	372
425 µm	12-28	20	132	240
150 µm	6-16	20 - a	132 - b	24 – 96
75 µm	4-8	2 – 8 (a)	24 – 96 (b)	0

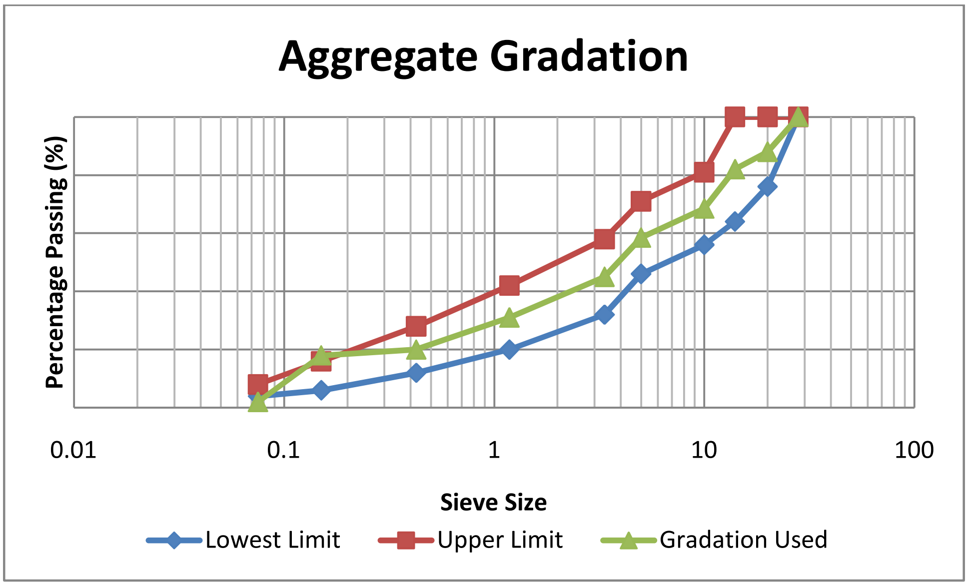

Figure 3.9 Aggregate Gradation

3.6 Aggregate Properties

3.6.1 Specific Gravity

In determining of mixture properties, it is required to calculate the specific gravity of composed material. The coarse and fine aggregates specific gravity was determined by using the Ultrapycnometer 1000. The latest specifications for this test are given in BS 812: Part 107. The Ultrapycnometer device is shown in Figure 3.10.

Figure 3.10 Ultrapycnometer

Table 3.4 Properties of Aggregates

Material	Property	Value	Ultrapycnometer
Coarse Aggregate	Bulk Specific Gravity	2.717	2.779
	Specific Gravity on SSD	2.668	
	Water Absorption (%)	0.47	
Fine Aggregate	Bulk Specific Gravity	2.710	2.797
	Specific Gravity on SSD	2.533	
	Water Absorption (%)	4.4	

The specific gravity of coarse and fine aggregate in this study used the specific gravity results were obtained from the Ultrapycnometer apparatus. The specific gravity results are showed in Table 3.4. It refers from previous studies have been done by Kreb and Walker who suggested to use effective specific gravity for most practical work [58]. The assumption is that the permeable voids in the bulk density do not penetrate the asphalt. On the other hand the density, permeable voids filled with asphalt in common with such water penetration. The Ultrapycnometer results give higher values than the British Standard method because it uses helium gas as a means of measurement. Helium can penetrate deeper into the pores than water, thus making the smaller measured volume of the particles [59].

3.6.2 **Flakiness and Elongation Index Test**

The aim of flakiness and elongation index test is to measure particle shape of coarse aggregate. In bituminous mixtures, flaky aggregate reduce aggregate interlocking. It also can cause crack and break up during compaction by rolling. The procedure to conduct this test refers to BS 812: Part 105. The result of flakiness and elongation index test is shown in Table 3.5

Table 3.5 Flakiness, Elongation Index Test and LA Abrasion Test results

Type of Test	Result
Flakiness Index Test	13.4 %
Elongation Index Test	27.1 %
Los Angeles Abrasion Test	16.1%

3.6.3 **Los Angeles Abrasion Test**

The Los Angeles (L.A.) abrasion test is a test method used to measure aggregate toughness and abrasion characteristics. Aggregate abrasion characteristics are important because aggregates' used in the pavement must resist crushing, degradation and disintegration in order to produce a high quality HMA. This test refers to BS 812: Part 113: 1990. The coarse aggregate sample retained on the No. 12 (1.70 mm) sieve is subjected to abrasion, impact, and grinding in a rotating steel drum containing 12 steel balls which has weight around 300 grams of each. After being subjected to the rotating drum, the weight of aggregate that is retained on a No. 12 (1.70 mm) sieve is subtracted from the original weight to obtain a percentage of the total aggregate weight that has broken down and passed through the No. 12 (1.70 mm) sieve. The result of Los Angeles Abrasion test is shown in Table 3.5.

3.7 Fillers

The types of filler used in this study are Ordinary Portland cement (OPC) and Hydrated Lime (HL). The concentrations of each filler used in the mixtures were 2%, 4%, 6% and 8% of the total weight of the aggregate. The fillers used in this study had 100% passing through the 75 μm B.S sieve. The fillers were dried in the oven at 105^{o}C for 24 hours before mixing with the aggregate and bitumen to produce a homogenous bituminous mix.

3.8 Filler Properties

Determining the physical and chemical characteristics of the filler was included in the filler properties test. The physical characteristics of filler such as particle density were determined by using Ultrapycnometer 1000. Meanwhile the physical appearance of filler was determined by using the scanning electron microscopy (SEM) respectively with 300 and 5000 times magnifications. The chemical constituents were determined by X-ray fluorescence (XRF) and X-ray Diffraction (XRD) technique. All filler samples used pass the 75 μm B.S sieve totally.

3.8.1 **Specific Gravity Test**

The fillers specific gravity were determined by using the Ultrapycnometer 1000. The most recent specification for these test is given in BS 812 : Part 107. The Ultrapycnometer device is shown in Figure 3.10. The result of specific gravity value is shown in Table 3.6

Table 3.6 Specific gravity test result

Type of materials	**Specific gravity**
Ordinary Portland Cement (OPC)	3.367
Hydrated Lime (HL)	2.723

Mineral fillers have been used to fill in the voids between the aggregate particles and to meet specified gradations for Hot Mix Asphalt (HMA). The interactions between the aggregate and filler contribute to the reinforcement of bituminous mixture. The physical and chemical properties of filler are described in detail as follows.

3.9 Physical Properties

The physical properties of fillers included density, particle shape, and particle size can be analyzed by using the X-ray fluorescence (XRD) and Scanning Electron Microscope (SEM).

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

X-ray Diffraction is a technique used to characterise the crystallographic structure, crystallite size (grain size), and preferred orientation in polycrystalline or powdered solid samples. This technique is based on the elastic scattering of X-rays from structures that have long range order. It may also be used to characterize heterogeneous solid mixtures to determine relative abundance of crystalline compounds [60].

Based on Bragg's law, $n\lambda = 2d\sin\theta$, it will leave only the lattice plane spacing as variable by controlling the wavelength which varies and continuously measures the incident angle. Thus, whenever a constructive interference is observed, at that point, a fundamental spacing parameter for the mineral of interest can be calculated [61]. The illustration of XRD process is shown in Figure 3.11. Another finding by Ishai, Craus and Sides have revealed that in analyzing the relationship between the optimum bitumen of the mastic (*a factor*) and the basic properties of filler, the relationship between specific surface, geometric irregularity, and heat of adsorption were significantly related with *a factor* [23]. The XRD machine is shown in Figure 3.12.

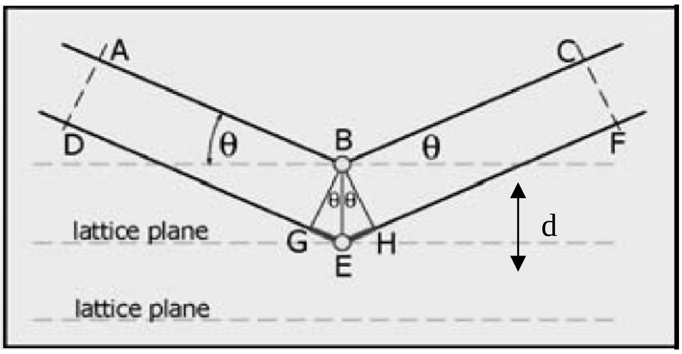

Figure 3.11 Geometry of X-Ray Reflection [33]

Figure 3.12 X-Ray Diffraction Machine

Using x-rays generated from a copper target and nickel filter, the amorphousness degree of material samples can be judged by the intensity or average height of the diffused band between 15° and 26° values of 2θ [62].

3.9.2 **Scanning Electron Microscope (SEM)**

The Scanning Electron Microscope can be used to study the surfaces of solid object [63]**.** It uses electron to depict an image rather than light. The electron beam is bent by electromagnets that results in an image on a screen. It is produced by heating of a metallic filament in electron gun. Then this electron beam will abreast with a vertical path through the column of the microscope and will pass the electromagnetic lenses, focusing and directing the beam to the sample. Backscattered electron and secondary electron are ejected from the sample when the electron beam hits the sample. The detectors will collect and convert these secondary and backscattered electrons to a signal that is displayed on a display screen [63]. Some researchers have mentioned that the filler geometric irregularity can be evaluated either by microscopic inspection or particle dimensional analysis [21]. Geometric irregularity is a property which expresses a combination of shape, angularity, surface texture and open porosity. All are related with specific surface of the filler particle.

3.10 Chemical Properties

The chemical composition of fillers can be predicted by using the X-ray fluorescence (XRF) apparatus. It is believed that it can influence the performance of asphaltic concrete mixture [18] [64]. The various chemical compositions of fillers can have influence on different characteristic of filler.

3.10.1 **X-Ray Fluorescence (XRF)**

X-Ray Fluorescence (XRF) is usually used by some researchers to analyze the chemical composition of material. It provides a deep comprehension about the chemical composition of the tested material to describe the research outline and analysis. X-Ray Fluorescence is named as the process of emissions of characteristic x-rays. The X-Ray either can be absorbed by the atom or scattered through the material when a primary X-Ray excitation source from an X-Ray tube or a radioactive source strikes a sample. The process in which an x-ray is absorbed by the atom by transferring all of its energy to an innermost electron is called the photoelectric effect. In this process, electrons are ejected from the inner shells to create vacancies in case the primary x-ray had sufficient energy. These vacancies present an unstable condition for the atom. When the atoms return to a stable condition, electrons from outer shells are transferred to the shell. This process will release the characteristic x-ray, whose energy is the difference between the two binding energies of the corresponding shells. Because every element has unique energy levels, each element produces x-rays at a unique set of energies to allow a certain person measuring the elemental composition of a sample non-destructively. Analysis using x-ray fluorescence is called "X-ray Fluorescence Spectroscopy" [65].

Figure 3.13 shows that an electron in the K shell is plugged out from the atom by an external major excitation x-ray when a radiation from x-ray tube or radioisotope comes. It creates a vacancy for an electron from the L or M shell to "jumps in" filling the vacancy. During this process, it radiates a unique characteristic x-ray to this element and turns to produce a vacancy in the L or M shell. This process allows elemental composition measurement of a sample [65]. ASTM standard specified that CaO content in hydrated lime when used in asphaltic mixtures must not to less than 90% in content [66]. The XRF machine is shown in Figure 3.14.

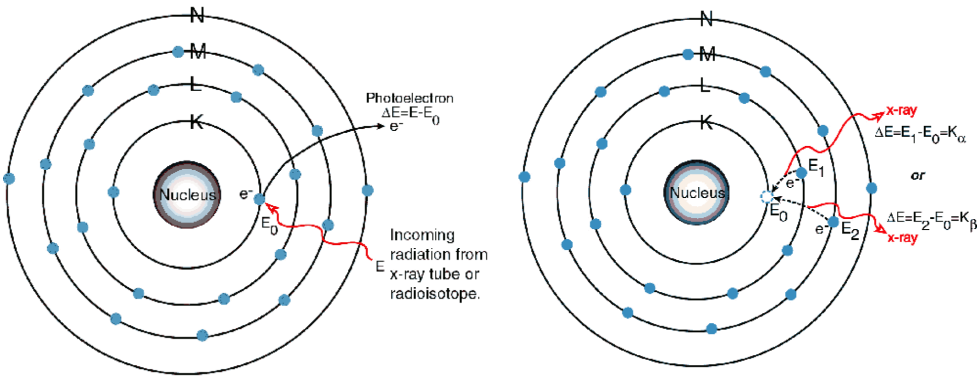

Figure 3.13 X-Ray Fluorescence Process [24]

Figure 3.14 X-Ray Fluorescence Machine

3.11 Mixture Preparation

The mixture preparations consist of mixture design and samples preparation. The mixture preparations were conducted to perform the basic characteristics of mixture that were used in the analysis of the mixture performance.

3.11.1 **Mixture Design**

Two types of filler, ie Ordinary Portland Cement (OPC) and Hydrated lime (HL) were used in the preparation of the mixture. For each filler type, there were three samples prepared for each bitumen content ranges between 4% - 6.5% with an increase of 0.5%. The filler content were varied from 2% – 8% with the increment of 2%. Mixtures were also made for filler combination of both HL and OPC which involve filler content 0%HL-8%OPC, 2%HL-6%OPC, 4%HL-4%OPC, 6%HL-2%OPC and 8%HL-0%OPC.

3.11.2 **Specimen Preparation**

For the Marshall Specimens preparation, 3 samples were prepared for each bitumen content which involve 3600 grams of aggregates including coarse aggregates, fine aggregates and filler were mixed. The heated and mixed sample was poured into a heated mould with a diameter of 100 mm and was compacted using Servopac

Gyratory Compactor (SGC) for 300 gyrations with 600 KPa of pressure force. The purpose of using SGC rather than Marshall Compactor is to simulate the reasonable degree compaction of bituminous material which actually takes place in site. The SGC is shown in Figure 3.15.

Figure 3.15 Servopac Gyratory Compactor

3.12 Mixture Properties

In order to analyze the effect of HL and OPC in bituminous mixtures, laboratory testing is needed to reveal effect of both filler. Shell (2003) has stated that there are three (3) types of test in asphalt testing, namely fundamental, simulative and empirical tests [2]. In this study Marshall Test represents empirical test. While Beam Fatigue Test and Dynamic Creep Test represent for fundamental test and simulative test were represented by Wheel Tracking test.

3.12.1 **Marshall Test**

The basic concepts of the Marshall Mix design method were originally developed by Bruce Marshall of the Mississippi Highway Department around 1939 and then refined by the U.S. Army Corps of Engineering. The Marshall method seeks to select the binder content at a desired density that satisfies minimum stability and range of flow values [67]. Marshall Stability is the maximum load that a specimen can withstand at a loading rate of 50.8 mm/minute tested at a temperature of 60°C. Basically, the load is increased until it reaches a maximum when the load just begins to decrease. The loading is stopped when the maximum load is recorded. During the loading, an attached dial gauge measures the specimen's plastic flow as a result of the loading.The flow value is the amount of deformation of the specimen at the maximum load. The flow value is recorded in 0.25 mm (0.01 inch) increments at the same time the maximum load is recorded. Previous study stated that the addition of mineral filler in asphaltic concrete mixtures can increase the stability value in bituminous mixtures [68].

The mix design methods use density and voids to determine basic HMA physical characteristics. These densities are then used to calculate the volumetric parameters of the HMA, i.e. voids in mineral aggregate (VMA), voids filled with bitumen (VFB), and air voids (AV). Voids in mineral aggregate (VMA) is the volume of inter granular void space between the aggregate particles of a compacted paving mixture that includes the air voids and the effective asphalt content, expressed as a percent of the total volume of the specimen. When VMA is too low, there is not enough room in the mixture to add sufficient asphalt binder to adequately coat the individual aggregate particles. Void filled with bitumen (VFB) is the portion of the voids in the mineral aggregate that contain asphalt binder. This represents the volume of the effective asphalt content. While air voids (AV) represents the total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture, expressed as a percent of the bulk volume of the compacted paving mixture. Marshall Stiffness which is Marshall Stability divided by flow is used to characterize the stiffness of the bituminous mixture. The optimum bitumen content (OBC) is finally selected based on the numerical average of Marshall Stability, stiffness, density analysis and void analysis.

The equation to obtain the density, stiffness, air voids (AV), voids in mineral aggregate (VMA), and voids in filled with bitumen (VFB) are shown below:

$$Density = \frac{Wair}{Wair - Wwater} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3\text{-}1$$

$$VMA = 100 - \%\ Volume\ of\ Total\ Aggregate \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3\text{-}2$$

$$VFB = \frac{\%\ Volume\ of\ Total\ Binder}{\%\ Volume\ of\ Total\ Aggregate} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3\text{-}3$$

$$Air\ Void = 100 - (100 \times (Bulk\ Density / Max\ Density\ Theorities)) \quad \ldots\ldots\ldots\ldots\ldots 3\text{-}4$$

$$Stiffness\ (Marshall\ Quotient) = \frac{Stability}{Flow} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3\text{-}5$$

The Marshall test was conducted in accordance to BS 598:1985 [69]. The procedure to obtain the stability and flow were started with conditioning the specimen in a 60^{o}C water bath for 30-40 minutes. The testing was conducted using a Marshall Testing Machine as shown in Figure 3.16. Then the data of stability and flow were recorded. The Stability correlation ratios are provided in AASHTO T-245 to adjust the values of the stability based on either volume or thickness consideration.

Figure 3.16 Marshall Testing Machine

Although the Marshall Test has been widely used; but still have limitations for measuring the resistance to permanent deformation [34] .

3.13 Performance Test of Asphalt Concrete Mixtures

3.13.1 **Permanent Deformation**

The wheel tracking test and dynamic creep test were applied to characterize permanent deformation of mixture variations. Both tests were subjected to the different types of specimens.

3.13.1.1 Wheel Tracking Test

The principal function of the Wheel Tracking Test is to determine the resistance of asphalts to plastic deformation, i.e. rutting [70]. Test specimens can be either cores cut from the highway or slabs prepared with a laboratory compactor. Above of that specimen a loaded wheel tracks with specified conditions of load, speed and temperature is applied while the effect of the rut profile is monitored continuously during the test.

The test measures the rutting under the wheel over a period of time. It runs backward and forward across a bituminous specimen and forms a longitudinal rut in the specimens. Test results are expressed as the change of surface deformation with variation of time. The relative deformation (RD) is defined as a slope between deformations at 45 and 60 minutes test times. Besides influenced by temperature and speed of loading of the test [71], the rut depth in bituminous mixture is also influenced significantly by binder content and binder penetration [72].

The permanent deformation characteristic of the mixtures was determined using The Wessex Wheel Tracker machine. It provides a fully automatic calculation of the tracking rates. The testing procedure was conducted according with the specification of BS 598-110: 1998 [73]. The rut depth versus cycle of loading parameters was plotted as result of the test. The apparatus of wheel tracking can be shown in Figure 3.17.

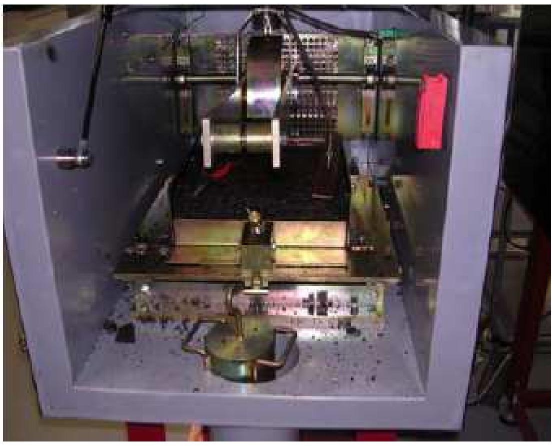

Figure 3.17 Wessex Wheel Tracker device

The wheel tracking specimens were prepared by mixing approximately 10 Kg of aggregates at the optimum bitumen content. The materials were mixed by using a mixer at a controlled temperature of 160^{o}C. The sample was then poured into a 305 mm x 305 mm x 50 mm mould and then was compacted by a hand compactor. All wheel tracking specimens were compacted in two layers with the same power of hand compactor. Two samples were prepared for each mixture variation.. The specimen for wheel tracking is shown in Figure 3.18.

Figure 3.18 Wheel Tracking test sample

An actual wheel of 200 mm diameter and 50 mm width with applied load of 520 N is used in this test. The wheel runs backward and forward across a bituminous specimen bedded in a steel base plate and held in place by plywood clamping blocks at the frequency setting of 42 wheel passes/minute. This test was carried out at temperature of 40^{o}C. The wessex software recorded the total rut depth after a number of wheel passes for 45-minute loading. Then the wheel tracking test results were compared to the dynamic creep test results in order to verify the effect of filler on the permanent deformation of the bituminous mixture.

3.13.1.2 Dynamic Creep Test

The creep test is one of the tests used to determine the permanent deformation of bituminous mixture. The dynamic creep test was conducted by using the IPC Global Universal Testing Machine (UTM) 4-19. This device measures the deformations in the same axis using Linear Variable Displacement Transducers (LVDTs). It applies a repeated pulsed uniaxial stress/load to a mixture specimen. A graph of permanent deformation (mm) versus time cycles can then be plotted to describe the relationship between permanent deformations (mm) versus time cycles. The British Standard DD226 [74] was referred to conduct this test with the following specifications:

a. Preload Option

- Stress: 12 kPa
- Holding Time: 120 s

b. Loading Options

- Wave shape: square pulse
- Pulse width: 1,000 ms
- Rest Period: 1,000 ms
- Contact Stress: 2 kPa
- Deviator Stress: 100 kPa

c. Termination Option

- Axial load reaches 30,000 micro-strain
- 1,800 loading cycles

The creep specimen has a similar dimension to the Marshall specimen. 1200 gram of coarse aggregate, fine aggregate and filler were mixed with certain bitumen based on the optimum bitumen content (OBC) results that obtained from the Marshall test. The sample was then compacted by using a Servopac Gyratory Compactor for 300 gyrations with 600 KPa of pressure force. Three specimens were prepared for each mixture variation. The creep test specimen is shown in Figure 3.19.

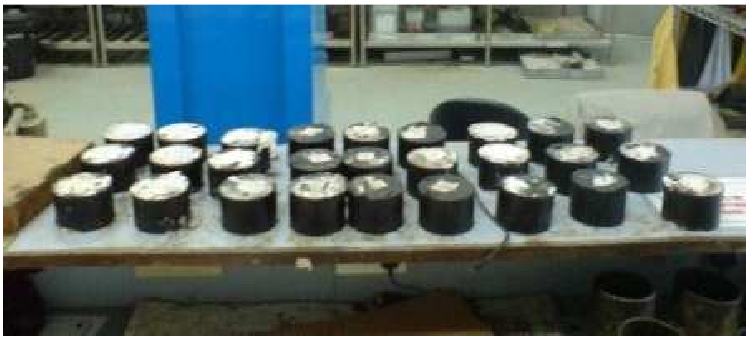

Figure 3.19 Dynamic Creep samples

The creep test was conducted at temperature of 40°C for 1 hour loading. Previously the specimen was kept at the same temperature approximately for 1 hour before testing. The dynamic creep test apparatus is shown in Figure 3.20.

Figure 3.20 Dynamic Creep Test device

After the specimen was set up on the jig of the creep test apparatus, a conditioning load of 12 kPa was preloaded to the specimen at the test temperature for 2 minutes, and the Universal Testing Machine (UTM) 4-19 software would record any axial deformation during testing. The 1800 load duration cycles of the test are applied for the specific time of loading. British Standard DD226 [74] is used to specify the rest period and applied stress. The pulse width 1,000 ms, rest period 1,000 ms and contact stress 2 kPa are proposed for the test parameters. The outcome results of creep test are plotted graph as a function of the rut depth versus time loading of dynamic creep specimens.

3.13.2 The Beam Fatigue Test

The beam fatigue test is the one of methods that has been developed for the fatigue testing of bituminous mixtures. In this subchapter only the beam test with third point loading is described. The advantage of the three point loading is the existence of a bending moment over the middle third of a specimen [75].

There are two types of controlled loading that could be controlled in a fatigue test i.e. either the stress or the strain. In controlled constant stress loading, the strain is increased following the number of repetitions. It is usually applied to a thick pavement (more than 152 mm or 6 in). However, failure occurs quicker with constant stress, because both stress and strain are normally larger for constant stress than constant strain. In addition the failure is easy to define using constant stress. Otherwise, in controlled constant strain loading, the load of stress is decreased following the number of repetition. It is usually used for a thin pavement that has a thickness less than 51 mm or 2 inch. The illustration is shown in Figure 3.21.

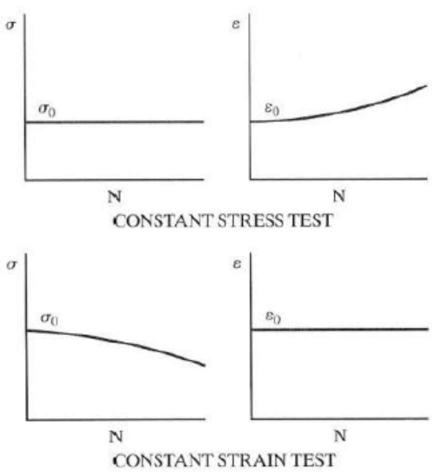

Figure 3.21 Types of controlled loading in Beam Fatigue test

For arbitrary failure criterion, for example, stress; is equal to 50% from the initial stress; constant strain is better to use. For pavement that has intermediate thickness, either constant stress or constant strain can be applied. For arbitrary failure criterion, for example, stress is equal to 50% from the initial stress, constant strain is used. In this test, it was necessary to select the range of sufficient stress that could make the specimens fail in the range of 1,000 to 1,000,000 repetitions.

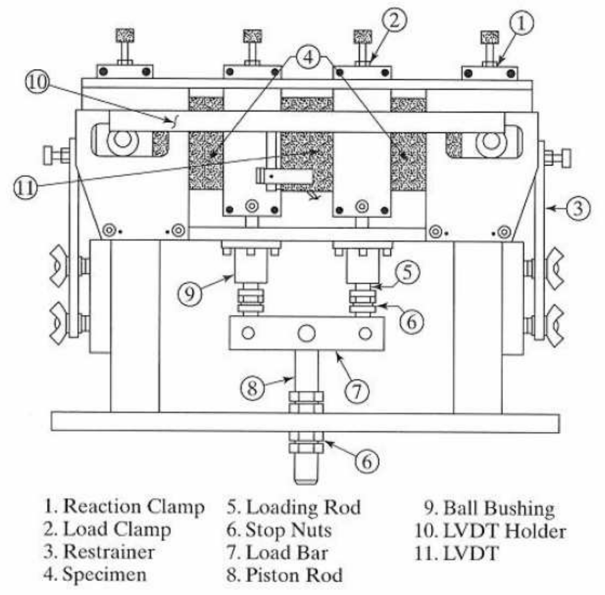

Figure 3.22 Schematic diagram of the fatigue test device

Figure 3.22 shows the schematic diagram of the fatigue test device. Types of beam fatigue test loading can be set into haversine or sinusoidal wave which has pulse width that ranges from 10 (100Hz) to 50.000 millisecond. The fatigue characteristic of bituminous mixture variations were investigated by using the beam fatigue test of the Universal Testing Machine (UTM 4-21). This was repeated flexural bending existing asphalt specimens. Then measure the force applied and the resulting deflection of the beam is to answer this test using a specimen of Linear Variable Displacement Transducers (LVDTs).

Approximately 7600 grams of total aggregates with bitumen at the optimum bitumen content and mixed in big mixer as shown in Figure 3.23 have been prepared for the beam fatigue specimens. The samples were poured into the 100 mm x 100 mm x 500 mm mould and were compacted by a hand compactor. All the beam fatigue specimens were compacted in two layers with the same power of hand compactor.

Figure 3.23 Beam Fatigue Test sample

The samples were then cut to obtain a dimension of approximately 50 mm x 65 mm x 380 mm for the fatigue test. Two samples were prepared for each mixture variation. This test was conducted at 20°C and a control strain mode was used. In the strain control mode, the deflection of the specimen is measured and the load is adjusted so that the specimen experiences a constant level of strain on each load cycle.

The parameters used in this test were:

a. Default poison ratio: 0.4

b. Loading conditions:

• Control mode: Sinusoidal strain

• Pulse width: 200 ms

• Frequency: 5 Hz

• Peak to peak: 100 micro strain

• Conditioning: 50 cycles

c. Termination conditions

• Termination stiffness: 50% of the initial stiffness or

• Stop test after 1,000,000 cycles

Every 10th cycle, the tabulated test data of the load and deformation were updated by the UTM 4-21 software. The beam fatigue test apparatus is shown in Figure 3.23.

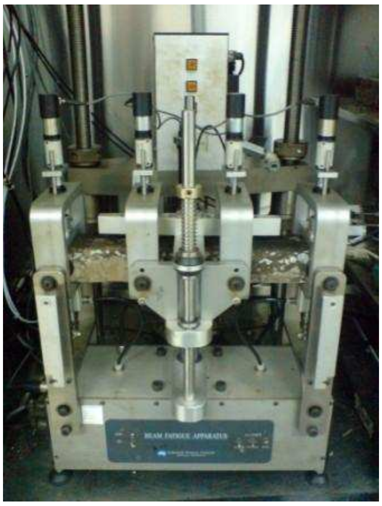

Figure 3.24 Beam Fatigue Test device

The results of beam fatigue test are plotted graph as a function of either initial strain or stress versus number of repetition loads on log scales. The plot can be approximated by a straight line and expressed as in Equations 3.6

$$N_f = c_2(\varepsilon_t)^{-f2} \quad \text{.........3.6}$$

In which N_f is the number of repetitions to failure, c_2 is a fatigue constant that is the value of N_f when $\varepsilon_t = 1$, and f_2 is the inverse slope of the straight line [75].

3.14 Mixture Optimization

The mixtures optimization was obtained by ranking the test result based on mixture performance and mixture properties. The output revealed the rank of the asphalt mixtures from the best to the worst according to either engineering properties results or performance test results. Then all aspect ranks were summarized.

CHAPTER IV

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter presents the test results and subsequent discussions on the results obtained in this work. The result would first describe the physical properties of the filler material studied. These include results from the X-Ray Fluorescence (XRF) test, The X-Ray Diffraction (XRD) test and the Scanning Electron Microscope (SEM) test.

4.2 Filler

4.2.1 X – Ray Fluorescence Test Result of HL and OPC

The X-Ray Fluorescence (XRF) test can be used to analyze the element and oxide composition of materials and the results are given in a percentage value [65]. This test was used to determine and analyse the material contents inside the filler used i.e. hydrated lime and ordinary Portland cement. The presence of various materials within the HL and OPC samples are given in Table 4.1 in the form of oxide content.

Table 4.1. Result of XR-F Test

TYPE of OXIDE	TYPE of FILLER	
	HL	OPC
	%	%
MgO	1.52	1.49
Al_2O_3	0.115	2.83
SiO_2	0.261	15.6
SO_3	1.21	3.63
K_2O	0.0455	0.26
CaO	96.1	71.4
Fe_2O_3	0.165	4.18
CuO	0.022	
SrO	0.0801	0.0341
P_2O_5		0.0731
TiO_2		0.114
MnO		0.151
ZrO_2		0.0125

The test result shows that both fillers have the same major oxide content, i.e. Quicklime (CaO). HL exhibited 96.1% of CaO whilst OPC exhibited 71.4% of CaO. In addition, the OPC filler also exhibited a high content of SiO_2 i.e. 15.6%, thus making CaO; SiO_2 as the major oxide component in OPC filler. ASTM [66] specifies that when HL is to be used as filler in bituminous mixtures, the CaO content must be in excess of 90%, this criteria is easily fulfilled with the HL used in this study. According to the chemical bonding theory, CaO displays ionic bonding, while SiO_2 displays covalent bonding [60]. Ionic bond possesses stronger bond between its ionic elements than covalent bond. The higher amount of CaO in HL is expected to display stronger bonding within itself than the OPC. This is expected to result in an influence stronger material and the performance of asphaltic concrete mixtures.

Abo-Qudais et al. compared the effect of basalt and limestone as aggregate in bituminous mixtures. They stated that limestone aggregate contains less SiO_2 than that of basalt. The presence of high silica content usually causes a reduction in the bond between the bitumen and aggregate. It can therefore be expected that bituminous mixtures using basalt as the coarse aggregate will be susceptible to stripping than mixtures made from limestone. Limestone aggregate is considered to bear positive charges on its surface while basalt bears a mixed charge. Usually stronger bonds are associated with aggregate having high electro-positive charges, this makes the basalt aggregate to be categorized as a hydrophilic (water loving) aggregate, while the limestone is categorized as hydrophobic (water hating) in nature [40]. Also Anderson and Goetz has stated that mixtures containing SiO_2 showed increase in viscosity than those containing $CaCO_3$ [19]. Thus, mixtures incorporating OPC is expected to produce stiffer matrix than mixtures using HL. This is crucial in that mixture where the strength of the mixture is derived from the stiffening of the mortar.

Previous studies however have shown that hydrated lime has a potential to act as a multifunctional modifier in bitumen. It improves the rheological properties of the asphalt binders as inert filler that will impart stiffening of the asphalt binder thus enhancing the mixture resistance to permanent deformation. Hydrated lime also has an active filler effect that gives a unique ability to reduce age hardening characteristics of asphalt mixtures by interacting with the polar compounds in the binder. This help to reduce the carboxyl-type oxidation products (carboxylic acid) formed during aging. As carboxylic acid is part of the asphaltene, this help reduce the ratio of asphaltene to the oxidation products formed during aging [2].

HL is also well known as an active-filler that can change the physical properties of a mix through its chemical interaction with the bitumen. Previous studies have reported that hydrated lime ties up a reduction in carboxylic acids and 2-quinolones in the bitumen with the formation of insoluble calcium organic salts; this process prevents reaction with a siliceous surface by forming water-resistive bonds. This phenomenon results in the formation of a strong water-resistant bond with the nitrogen groups in the bituminous mix [9] [11] [10] [12] [42].

4.2.2 **X – Ray Diffraction Test Result of HL and OPC**

The X-Ray Diffraction (XRD) test can be used to analyze the crystalline properties of a material. Graph patterns of the XRD analysis can show whether the material is amorphous, partially crystalline or crystalline. The gradual dense scatter in the XRD graph is used to indicate the amorphous state of a material. Figure 4.1 and Figure 4.2 show the result of the X-Ray diffraction test for both HL and OPC. As the graphs show a flat and sharp peak in its scatter, HL and OPC samples can be categorized as crystalline sample. A fully amorphous material is indicated with a smooth gradual scatter of the XRD graph.

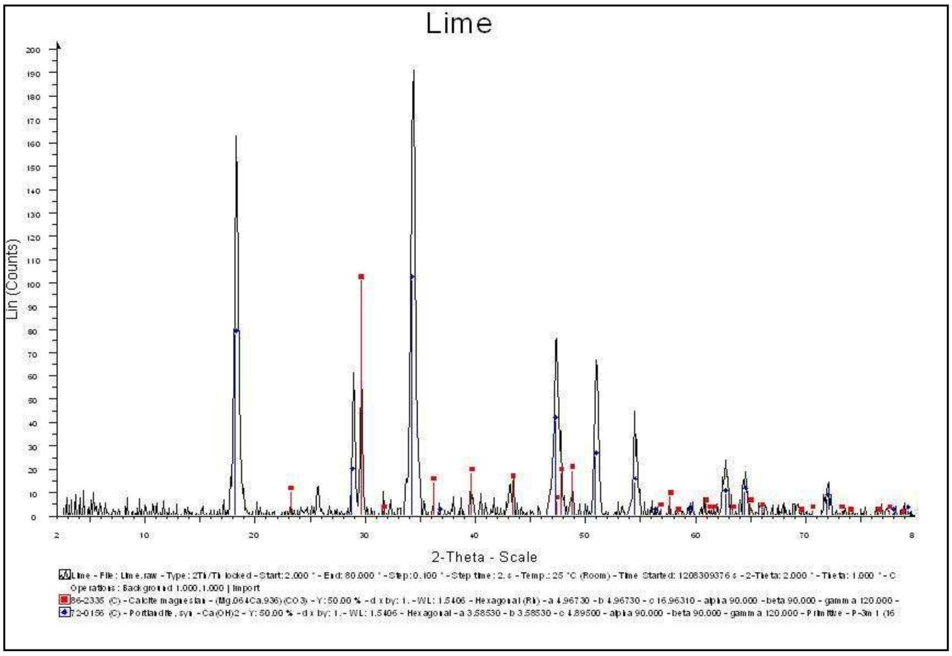

Figure 4.1 Result of X-Ray Diffraction Test of Hydrated Lime

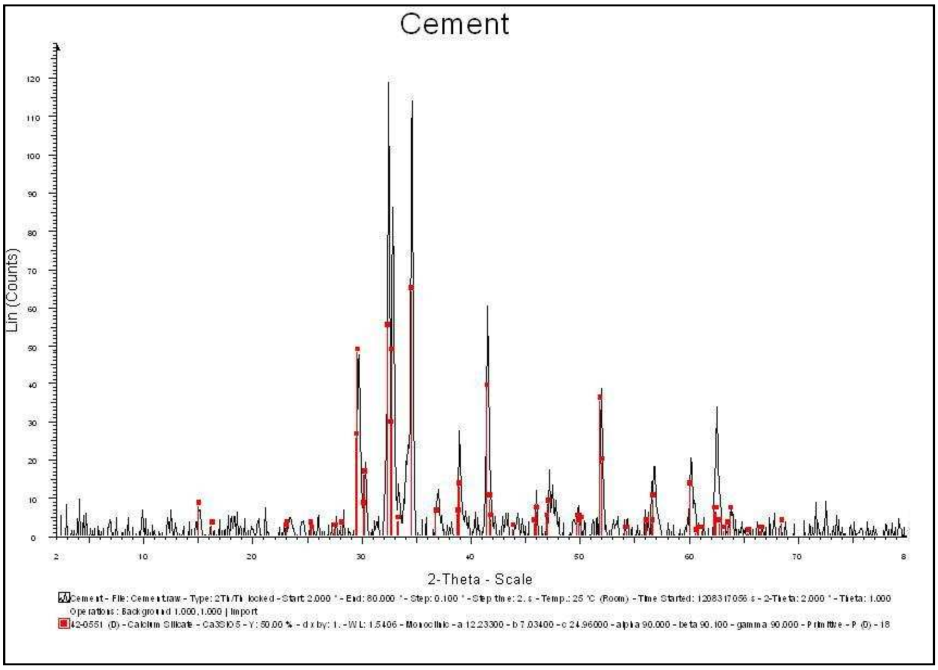

Figure 4.2 Result of X-Ray Diffraction Test of Ordinary Portland Cement

The XRD tests also provide the Ln value in the Y-axis and the angle of diffraction in the X-axis. The Ln value is a measure of the ability of the material to diffract X-Ray. The higher the Ln value, the greater the ability of particle to diffract the X-Ray. This also indicates a higher density of the crystal in the material tested. From the XRD test; the HL filler exhibited higher Ln value and a greater ability to diffract the

X-Rays as compared to the OPC filler, which indicates that the HL particles are stronger than the OPC particles [60]. The harder particles tend to increase the hardness of the bituminous mixtures, hence, increasing the stiffness of the binder in the mix [76].

4.2.3 Scanning Electron Microscope (SEM) Test Result of HL and OPC

The Scanning Electron Microscope (SEM) analysis was also carried out to describe the particle shape and particle size of the filler studied. It is believed that the filler physical properties will influence the properties of the resulting bituminous paving mixtures [16], [14]. The shape of the filler particle may influence the void filling mechanism in the mixture [20]. The test was performed using the LEO 1430 VP Inca X-Sight Oxford Instrument. The filler must be coated with gold atoms before the start of the test. The filler was then placed in the vacuum chamber inside the SEM. The SEM must be operated with specific pressure to facilitate the operation of filament and electron inside SEM. The physical appearance of the HL and OPC filler at 500x and 3000x magnifications as obtained from the SEM are shown in Figure 4.3 to Figure 4.6. These particle shape peculiar to each filler type is deemed to have an effect on the properties of the resulting bituminous mixtures.

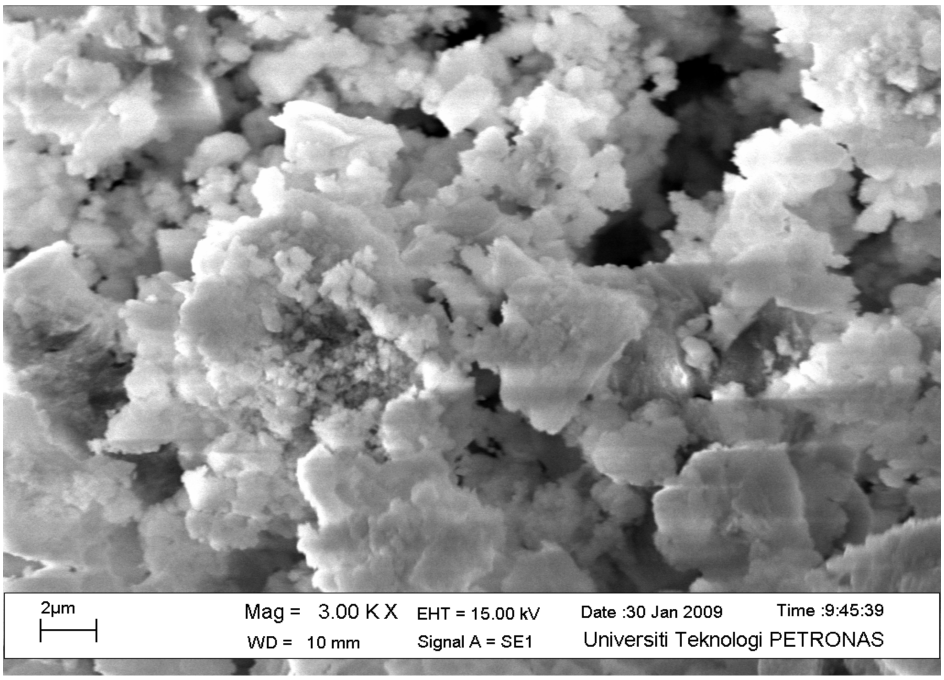

Figure 4.3 SEM Test result of Hydrated Lime in 3000x magnification

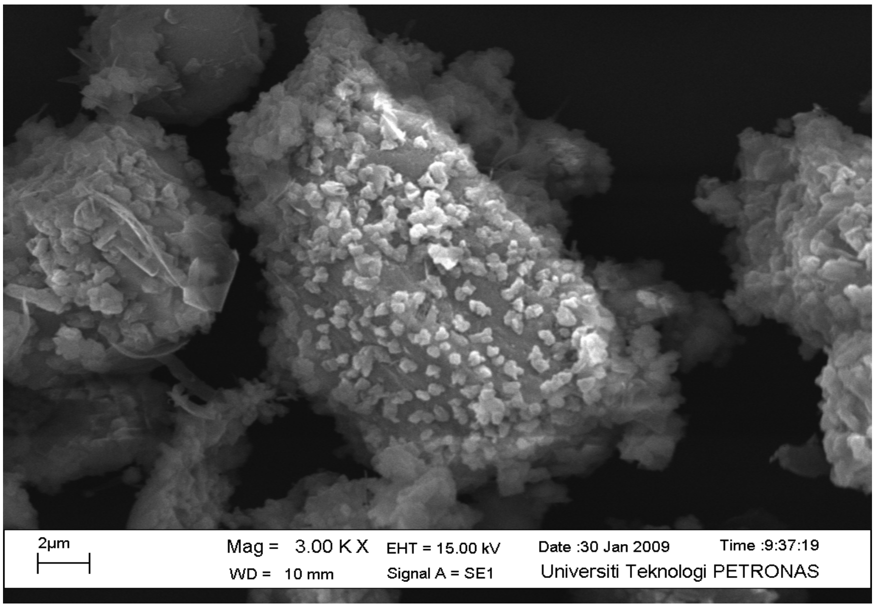

Figure 4.4 SEM Test result of Ordinary Portland Cement in 3000x magnification

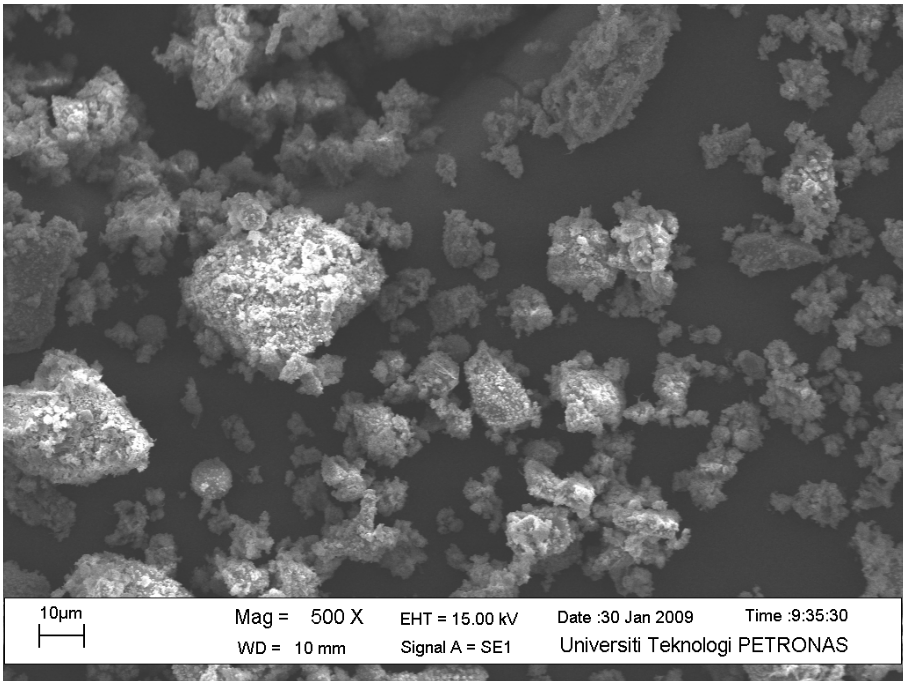

Figure 4.5 SEM Test result of Ordinary Portland Cement in 500x magnification

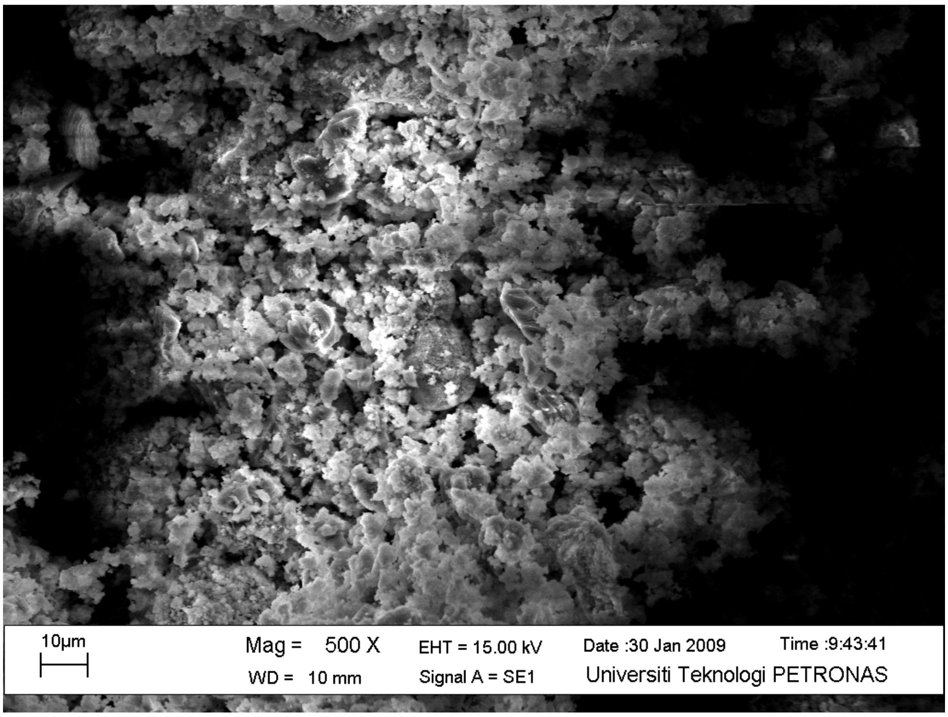

Figure 4.6 SEM test result of Hydrated Lime in 500x magnification

From the SEM test, it can be seen that the HL fillers have smaller particle size when compared to the OPC. It was also observed that the OPC fillers have very distinct spherical and oval shapes, while the HL are smaller and displayed irregular shapes. It can therefore be expected that HL particles have better ability to fill the pore in the asphaltic mixtures. This should result in a more dense mixture. The irregular shape of the fillers it also means that is capable of providing better interlock between the particles as compared to the asphaltic mixtures containing the OPC. The size of particles also has some effect on the performance of paving mixtures. Smaller particle tend to decrease the void within the bituminous mixture, which consequently increases the resistance to permanent deformation.

4.3 Optimum Bitumen Content (OBC)

This section discusses the effect of filler properties and proportions on bituminous mixture properties. In determining the engineering properties and Optimum Bitumen Content (OBC), all samples have been tested using the Marshall Mix design. In doing so, the physical and engineering properties of the mixtures such as Stability, Flow, Void in Mineral Aggregate (VMA), Air Void (AV) and Void Filled Asphalt (VFA) could thus be determined. The results of the test were then analyzed to fulfill the requirement of heavy traffic loading according to the requirements of the local JKR standards.

The JKR specifications specified that the maximum filler content in asphaltic concrete mixtures is 8%. Bituminous mix specimens were made with variation of the filler content from 2% to 8%. Mixtures were fabricated by two modes. The first considered comparison between filler content from 2% - 8% for both HL and OPC in increment of 2%. The second considered a filler content fixed at 8% having variations of 0%HL-8%OPC, 2%HL-6%OPC, 4%HL-4%OPC, 6%HL-2%OPC and 8%HL-0%OPC. This variation follows an equivalent variation in the content of the fine aggregate with the coarse aggregate content remained fixed. In determining the OBC, a total of 13 mixtures were prepared. 3 samples were prepared for each bitumen contents ranging from 4% to 6.5%. Each mixture was assigned a designated code based on the bitumen content, filler type and filler content. The requirements for asphaltic concrete mixture parameters as set by Jabatan Kerja Raya (JKR) Malaysia Standards [17] are shown in Table 4.2.

Table 4.2 Jabatan Kerja Raya (JKR) Malaysia Standards Requirements for AC Mixtures

Parameter	Wearing Course
Stability (S)	> 8000 N
Flow (F)	2.0-4.0 mm
Stiffness (S/F)	> 2000 N/mm
Air void in mix	3-5%
Void in aggregate filled with bitumen	70-80%

4.3.1 **Density of AC Mixtures**

Figure 4.7 shows the effect of variation of density for filler content from 2% - 8% versus bitumen content for both HL and OPC fillers. Figure 4.8 shows the effect of variation of density with bitumen content for filler content combination fixed at 8%. Variations of filler are given in the legend.

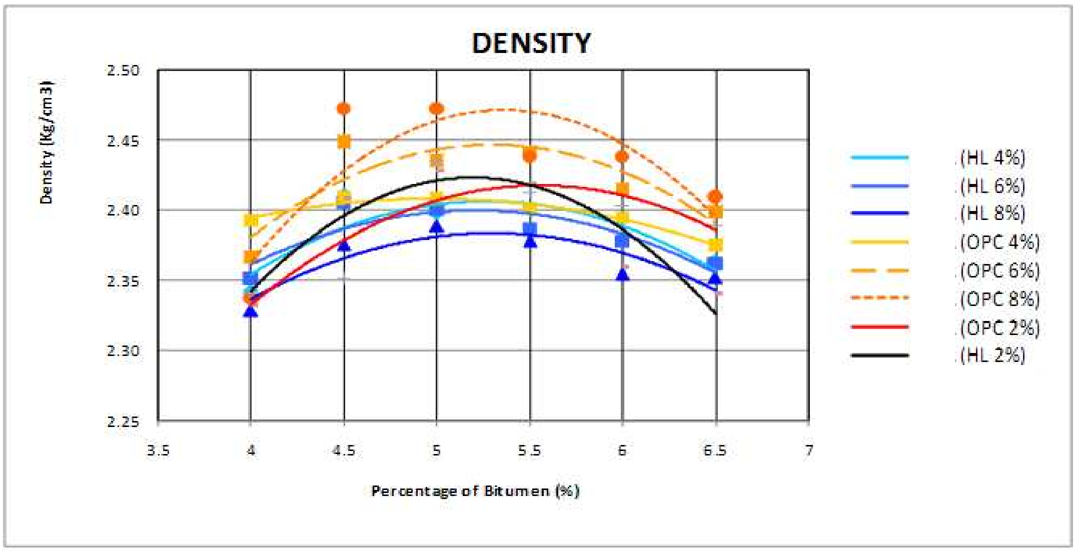

Figure 4.7 Density result of 2%- 8% fillers

Based on the results, the highest density is achieved by the asphaltic mixture containing 8% OPC filler. This trends then tend to decrease followed by the reduction of the OPC filler percentage contained within mixtures. This phenomenon may have happened because of the particle shape factor. The spherical and oval shapes of the OPC tend to show better void filling ability than the irregular shapes of the HL particle. This makes the density of mixtures containing the OPC filler to be denser than mixtures containing the HL filler. In addition this phenomenon may also be caused by the specific gravity factor. The OPC had higher specific gravity (3.37) than either HL filler (2.73) or the fine aggregate (2.8). The addition of the OPC filler into the asphaltic concrete mixture replacing the fine aggregate tends to influence the bulk density of the mixtures. This phenomenon has a reversible trend to the asphaltic mixtures containing HL as filler. The increase of HL percentage tends to decrease the densities of the resulting mixtures. This occurred because the replacement of the fine aggregate by HL which has a lower specific gravity than that of fine aggregate. In addition, the irregular shape of the HL filler when filling up the voids in the asphaltic concrete mix will result in a higher porosity and less dense mix.

These trends were also stated in previous research on fillers by Kallas and Puzinauskas. They tested eleven types of fillers using the Marshall Test. The proportioning of the mineral filler content in the bituminous mixture was based on the total volume of the total mineral aggregate. The results showed that overall asphaltic concrete mixtures containing OPC had higher density than asphaltic concrete mixtures containing HL [5]. Rigden stated that under such condition, the voids in the filler are just filled with binder. When there is excess binder, the density would be lower [20].

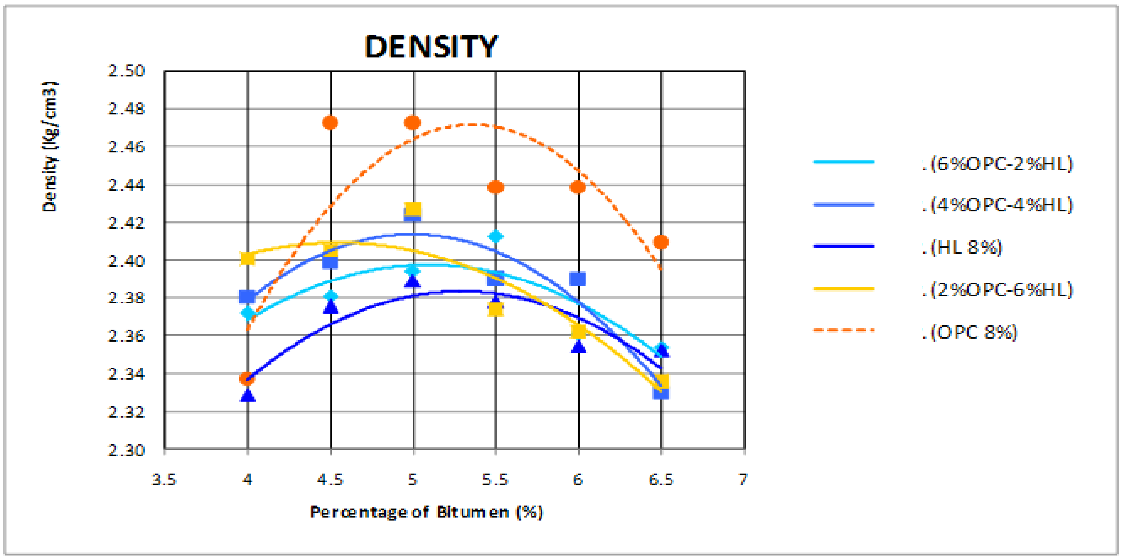

Figure 4.8 Density result value of mixtures combination of 8% filler

The density results for the combination of both filler are shown in Figure 4.8. The graph also exhibited the same behavior as that found previously. The density tends to increase up to a certain peak value before it starts to decrease with further addition of bitumen. In ascending order of density, the results are as followed: (i) asphaltic mixtures containing 8%; (ii) mixtures containing 4%OPC-4%HL; (iii) 2%OPC-6%HL; (iv) 6%OPC-2%HL; (v) asphaltic mixtures containing 8% HL. Apparently, the incorporation of both fillers at the balance composition of 4%OPC-4%HL resulted in the densest mixtures. This phenomenon is caused by the particle size factors. The HL which has smaller particle size than OPC particle fills the pore between the aggregate particles more efficiently, thus producing denser mixture.

4.3.2 **Air voids (AV) of Mixtures**

Air voids (AV) expresses the percentage of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture compared with the total volume of the mix. Based on the JKR standards, air voids requirements are set at a range of 3% up to 5%. However, most of the mixtures in this study have air voids greater than 5%. In this study, the JKR standard air void requirement was only fulfilled by mixtures containing 2% and 8% of OPC filler. The other percentage of OPC filler fail to fulfill the air void requirement. In HL mixtures, all mixtures containing 2%-8% filler content fail to fulfill the air void requirement of the JKR standards. In other hand, for the use of the HL filler, the compactive energy must be increased beyond the 300 gyratory revolutions used in this study. In addition, the increase in temperature of mixing will also help in achieving the porosity of the bitumen, thus making it easier to achieve a denser mix when compacted.

This phenomenon was also observed by Abo-Qudais which used a gyratory compactor in mixtures containing basalt as aggregate. All the samples obtained in his study exceeded the air void requirement [40]. Ishai et.al compared the performance of six (6) fillers namely glass beads, dolomite, sandstone, basalt, limestone and hydrated lime. Their results showed that for the same filler content, mixtures containing hydrated lime posses a higher optimum bitumen content and higher air voids than with limestone filler. These were caused by the much higher specific surface, bitumen absorption and geometric irregularity of the hydrated lime particles [23].

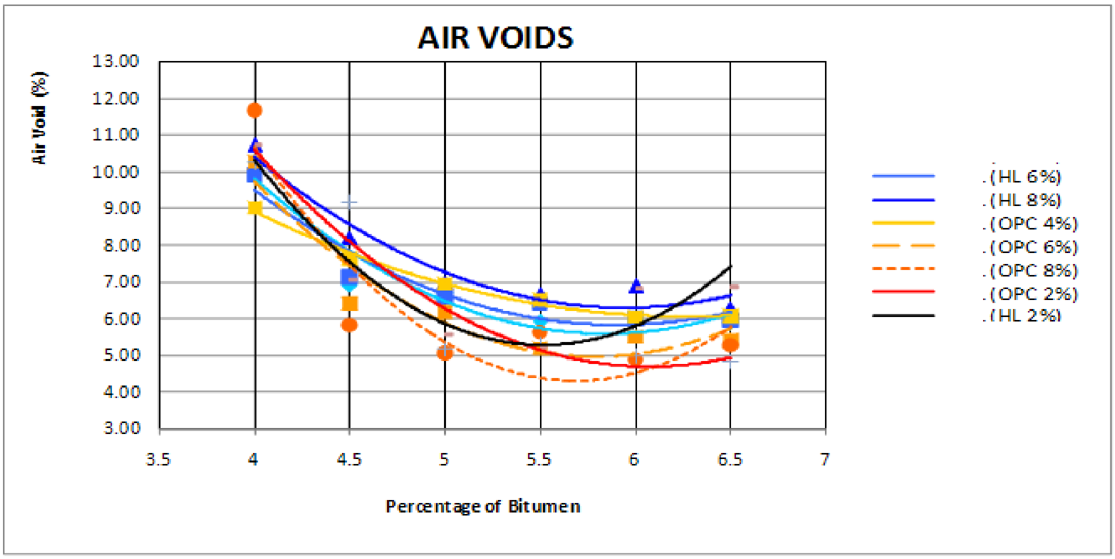

Figure 4.9 Air Voids result of 2%-8% fillers

The results of the variation of 2% - 8% of filler in air voids parameter are presented in Figure 4.9. Generally, air voids will decrease with increase of bitumen content. As the bitumen content is increased, the air voids decreases up to a point when further addition of bitumen content will cause the air void to increase. This is caused by the fact that addition of aggregate particles thus resulting in a decrease air void. When the bitumen has fully coated the aggregate, this will result in the densest condition in the mixture. The addition more bitumen will cause the aggregates to be pushed apart resulting in a higher porosity in the mix.

Based on Figure 4.9, the asphaltic concrete mixtures containing OPC have lower air voids than asphaltic mixtures containing HL filler. This can be understood by taking a look at the specific gravity (SG) of both fillers. Lower SG value results in higher particle amount of filler. The presence of a greater amount of filler in the mix affects the viscosity of the bitumen. For the same percentage of filler, mixtures containing HL have higher particle amount of filler than OPC mixtures. This makes bitumen in HL mixtures more viscous than OPC mixtures. Higher viscosity bitumen results in higher stiffness. It therefore makes harder for the bitumen to fill the permeable pores within asphaltic mixtures leading to higher air voids. On the other hand, the addition of the OPC percentage decreases the amount of air voids. This occurrence is caused by the OPC particle has spherical and oval shapes which make them easier to fill the mixtures pores. This will result in a lower air void, in contrast with filler particle that has irregular shape.

Even though HL mixtures have higher air void, based on the stability result, mixtures containing HL still shows higher stability value than OPC mixtures. This is caused by the ability of the HL as active fillers in bituminous mixtures. The stiffening that results from the addition of hydrated lime can increase the viscosity of the asphalt cement [9] [35]. In addition, the dispersion of the tiny hydrated lime particles throughout the mix makes the mix stiffer and tougher, thereby reducing the possibility that the bond between the asphalt cement and the aggregate will break mechanically [43].

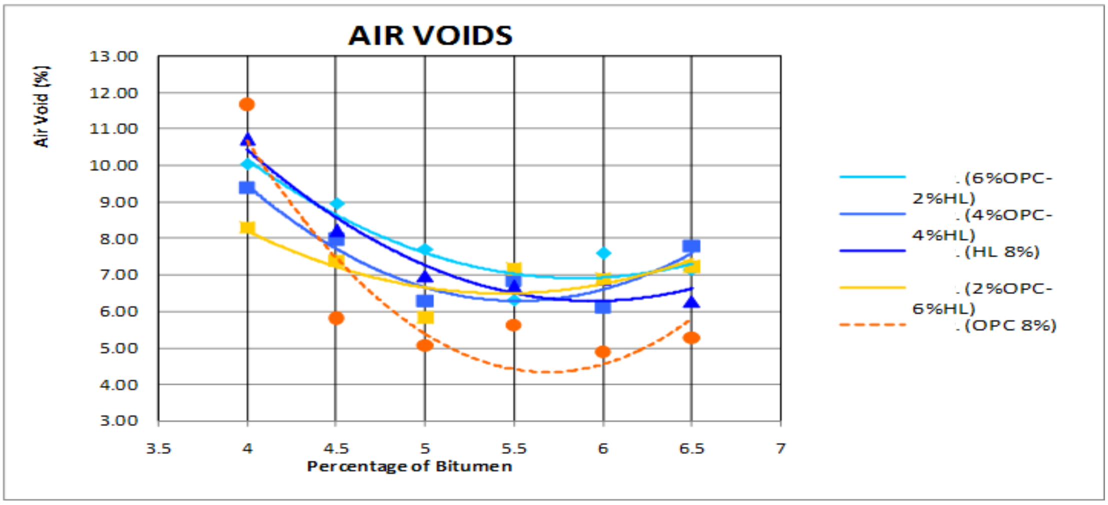

Figure 4.10 Air Voids result of mixtures combination of 8% filler

The air voids results for the same percentage of fillers are presented in Figure 4.10. Apparently the lowest air voids has been shown by asphaltic mixtures containing 8% OPC. The highest air voids occurred in mixtures containing 6%OPC - 2%HL. This phenomenon is related with previous analysis of the air voids in the mix. The minimum value of air voids in mixtures containing 8% OPC is caused by the particle shape of OPC as shown by the SEM result. The oval and spherical shape apparently has better void filling characteristics than irregular particle. Previous research [16], has suggested that the shape of the filler as being possible factors affecting the AV and VMA results.

4.3.3 **Marshall Stability**

The Marshall Stability provides a predictive measure for the Marshall mix design method. It is defined as the maximum load carried by a compacted specimen at a standard test temperature of 60ºC with a loading rate of 50.8 mm/minute (2 inch/minute). The load is increased until it reaches a maximum. When the load just begins to decrease, the loading on the specimen is stopped and the maximum load is recorded as the Marshall Stability value. JKR standard requires the minimum value of stability to be higher than 8 kN for heavy traffic loading. The stability results of all the mixtures are shown in Figure 4.11 and Figure 4.12 for variation of bitumen content from 4% - 6.5%.

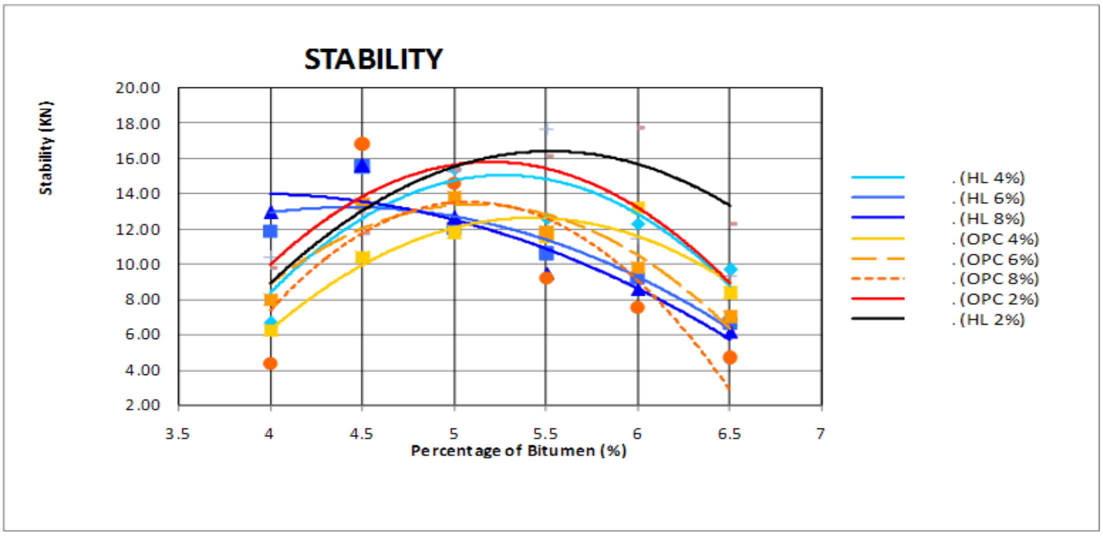

Figure 4.11 Stability result of 2%-8% fillers

From Figures 4.11, it can be observed that all stability trends increased together with the increase of bitumen content. Then it started to decrease after it had reached the maximum value. Based on both figures, in the 2 % and 4% of filler content, mixtures containing HL have higher stability values than mixtures containing OPC. On the other hand in the 6% and 8% of filler content, mixtures containing OPC showed higher stability value than mixtures with HL. Previous investigations by the Army Corps of Engineers stated that excess amount of fines particle produce crack in bituminous mixtures while being rolled. Especially in the warm weather, the pavement with excessive filler amount exhibited more cracking under load [24]. Based on the stability results, it seems like HL contributes higher stability in the range of 2-4 % filler content, while OPC in 6-8 % filler content. These results also can be related with specific gravity value results of both fillers, where the specific gravity of HL (2.73) is lower than the specific gravity of OPC (3.37). This means that for the same percentage of filler by weight, the particle amount of HL is greater than OPC. Thus, the excess amount of HL particles contributes to reduce the stability value in higher filler content i.e. 6-8%. It reduces the bitumen film thickness in mixtures and causes bonding reduction between the aggregates. Apparently HL has good contribution to enhance stability value of bituminous mixture in low percentage of filler content, while OPC give good contribution to stability value in high percentage of filler content.

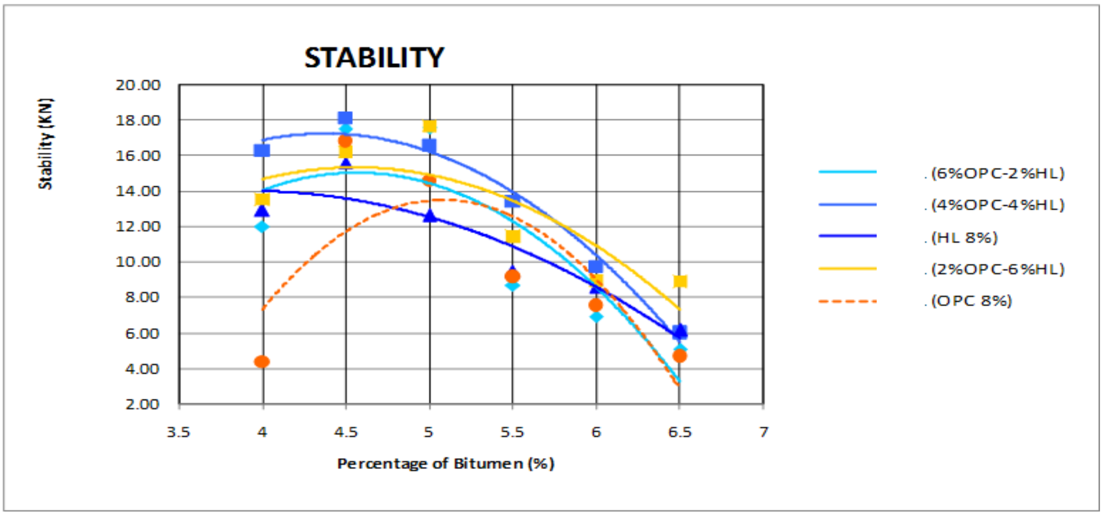

Figure 4.12 Stability result of mixtures combination of 8% filler

The incorporation of both filler mixtures showed that the incorporation of OPC and HL increase the stability of the mix. The maximum stability value has been achieved by incorporating 4%OPC-4%HL filler proportion. This is caused by the combination size of both filler resulting in a balance composition. As can be seen from the SEM result, HL has a smaller particle size than OPC. The combination of both fillers produces denser asphaltic mixtures. HL has irregular particle shape, while OPC particle has oval shape. Apparently the combination of both OPC-HL fillers resulted in better intelocking inside mixtures. Previous research also stated that hydrated lime can increase the rheological properties of asphalt binder as an inert filler that will impart in the stiffness of the bitumen and increases the resistance to permanent deformation [2] [9]. On the other hand, OPC containing SiO2 or known as silica, based on the data in a handbook of filler [76], it can be classified as hydrophobic oxides. When used as filler in asphalt mixtures, tend to susceptible in the water, increase stability result after immersion.

4.3.4 **Flow**

Flow characteristics give an indication the deformation of the bituminous specimen at a standard test temperature of 60ºC with a loading rate of 50.8 mm/minute (2 inch/minute). It is recorded together with the Marshall Stability value obtained from the Marshall Stability test. It does not however represent the actual permanent deformation performance of the mix since the analogous loading mechanism of that relate to actual permanent deformation. The JKR standard requires the range of flow values from the Marshall test from 2 - 4 mm. The flow results of all bituminous mixtures are shown in the Figure 4.13 and Figure 4.14 for different filler concentration and filler combinations.

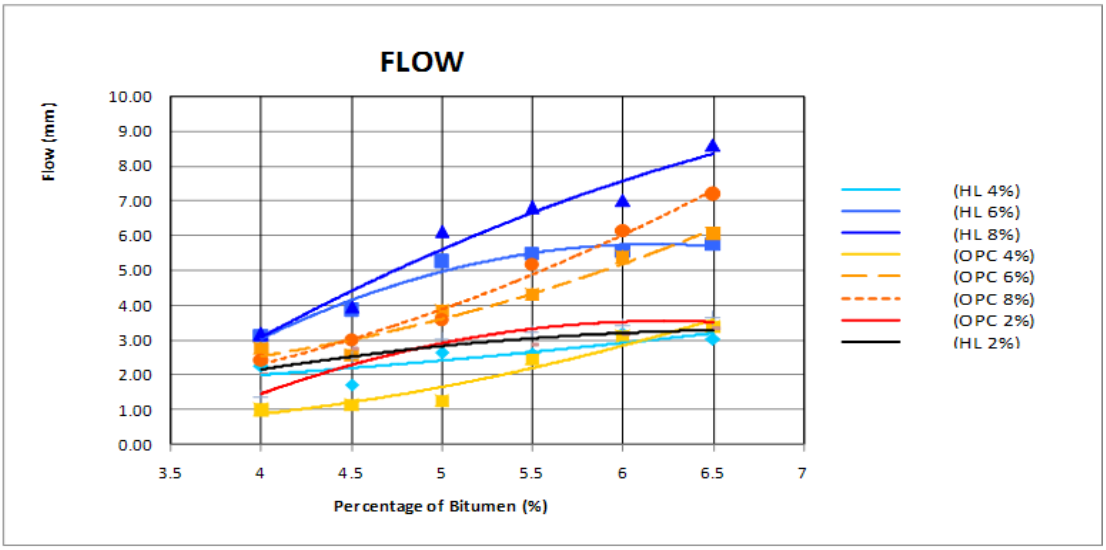

Figure 4.13 Flow result of 2%-8% fillers

The flow results generally increase with increasing bitumen content. It can be understood that adding bitumen will reduce an internal friction between the aggregate, permitting it to deform when load is applied. Figure 4.13 shows that for equal percentage of filler, asphaltic mixtures containing OPC filler had lower flow results than asphaltic concrete containing HL filler particles. These results can be related to the specific gravity of the particles; lower specific gravity of the HL particles resulted in greater particle amount for the same percentage weight. HL which has lower specific gravity value than OPC delivers greater particle amount in the same percentage. The increase of filler content will increase the aggregate surface area, reducing the asphalt film thicknesses that then make the asphaltic mixture easier to deform. Only 2-4% filler content of HL in this study fulfilled the JKR's flow requirement, while mixtures containing OPC filler fulfilled the JKR's flow requirement in the range of 6-8% filler content.

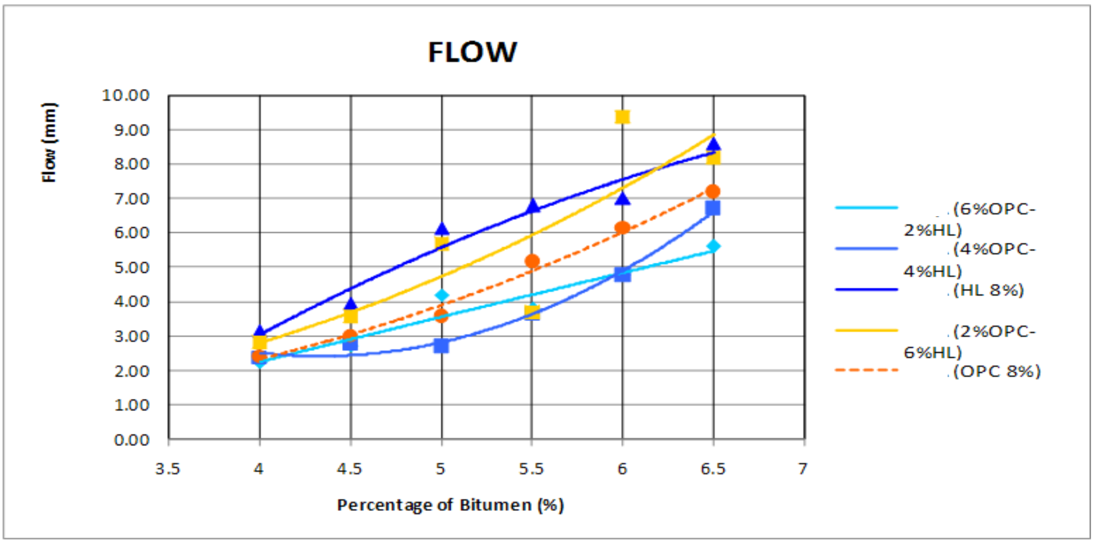

Figure 4.14 Flow result of mixtures combination of 8% filler

The flow results of mixtures containing combination of both filler showed that the incorporation of OPC-HL filler reduce the flow characteristic of the mix. Asphaltic concrete mixtures containing combination of 4%OPC-4%HL produced the lowest flow value amongs the sample. This phenomenon had similar trend with the stability value of asphaltic mixtures containing combination of both fillers. This is caused by the combination of both filler resulting in a balanced composition inside the mixtures. Combination of both fillers give double effects either mechanically or chemically to the mix. Previous studies have indicated that both fillers have dual role in bituminous mixtures. It was stated by Eriksen that Portland cement can increase the stability of bituminous mixtures by 250-300% over that of untreated hot-mix asphalt [33]. On the other hand HL filler can change the physical properties of a mix through its chemical interaction with the bitumen. A number of researches have reported that hydrated lime ties up the carboxylic acids and 2-quinolones in the bitumen with the formation of insoluble calcium organic salts; this process preventing these functionalities from reacting with a siliceous surface to form water-sensitive bonds. This phenomenon leaves important active sites on the siliceous surface to form strong water-resistant bonds with nitrogen groups in the bitumen that will enhance adhesion with aggregate [9] [11] [10] [12].

4.3.5 **Marshall Quotient**

Marshall Quotient is a parameter that measures the resistance of Marshall samples to deformation by an applied force. It reflects the stiffness of the bituminous samples when subjected to loading. It is obtained by dividing the stability with the flow value. The stiffness for all the mixtures are shown in Figure 4.15 and Figure 4.16 respectively for different filler content and combination of filler content up to 8%.. The graphs showed increasing stiffness along with increasing bitumen content until it reaches a maximum stiffness value before it starts to decrease.

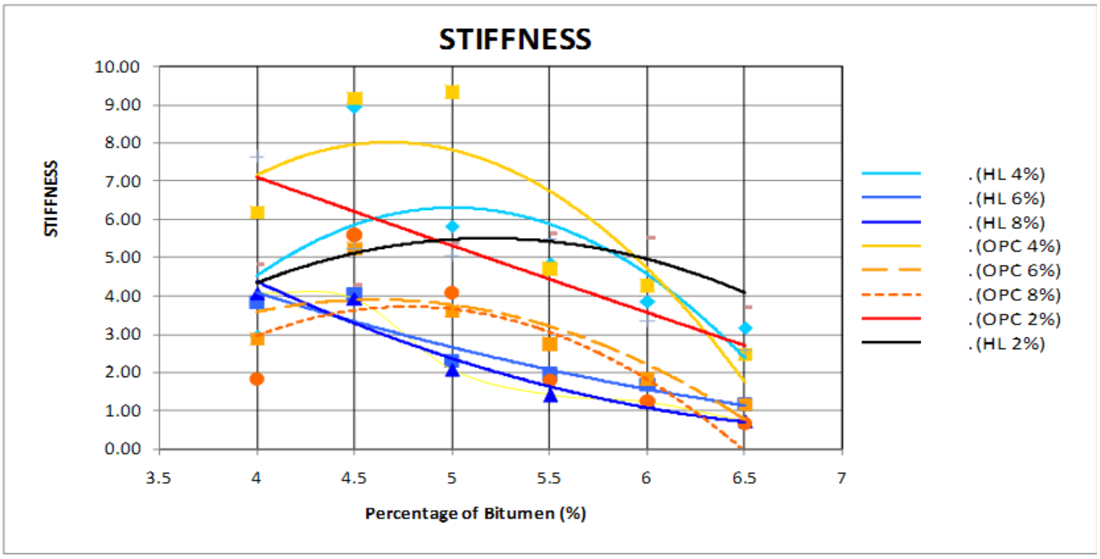

Figure 4.15 Stiffness result of 2%-8% fillers

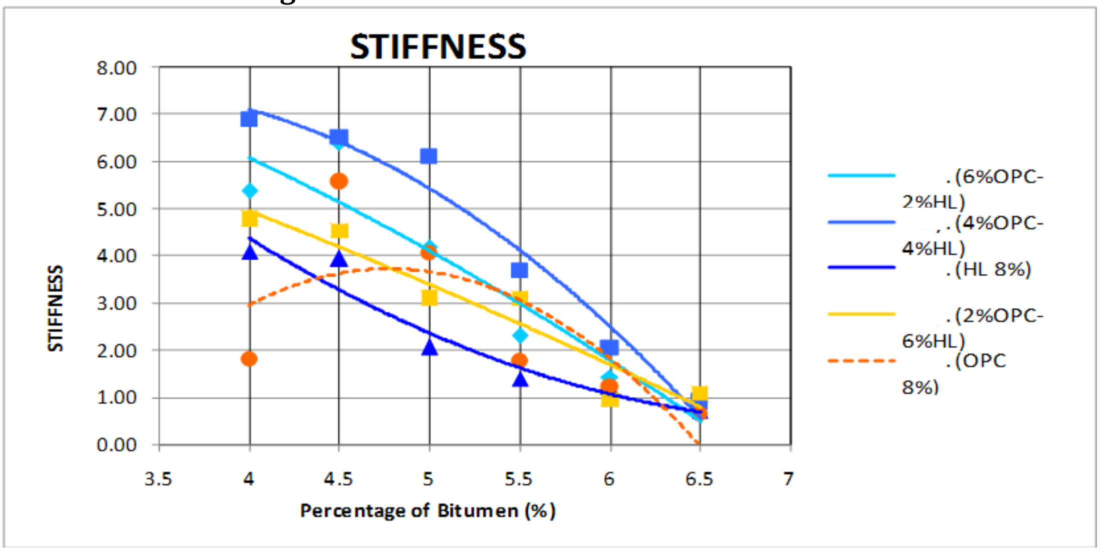

Figure 4.16 Stiffness result of mixtures combination of 8% filler

In the same percentage of filler content, the asphaltic mixtures containing OPC showed higher stiffness values than mixtures containing HL fillers. These trends are caused by the fact that the particle amounts of HL are greater than OPC as influenced by its lower specific gravity. The presence of greater particle makes the surface area of filler larger; therefore needing a greater amount of bitumen to coat them. It reduces the asphalt film thicknesses within mixtures and, thus, it decreases the stiffness. This trend was also noticed when comparing in the same filler content. The stiffness decreases when the percentage of filler was increased. The additions of filler percentage inside the asphaltic mixtures resulted in lower stiffness. In Figure 4.16, the incorporation of both fillers for the 4%OPC – 4%HL combination result in the highest stiffness among the bituminous mix samples. This phenomenon has a similar trend with the stability result. The balance composition combination size of the both fillers tend to make the asphaltic mixtures denser resulting in better intelocking inside the mix. However, this needs to be further verified via performance tests.

4.4 Optimum Bitumen Content of Mixtures containing HL and OPC

The optimum bitumen content was obtained by optimizing several parameters of mixtures namely density, VMA, Stability and Marshall Quotient (Stiffness). All these parameters conformed to the JKR Standards [4], except for VMA which followed the requirement by the Asphalt Institute [77].

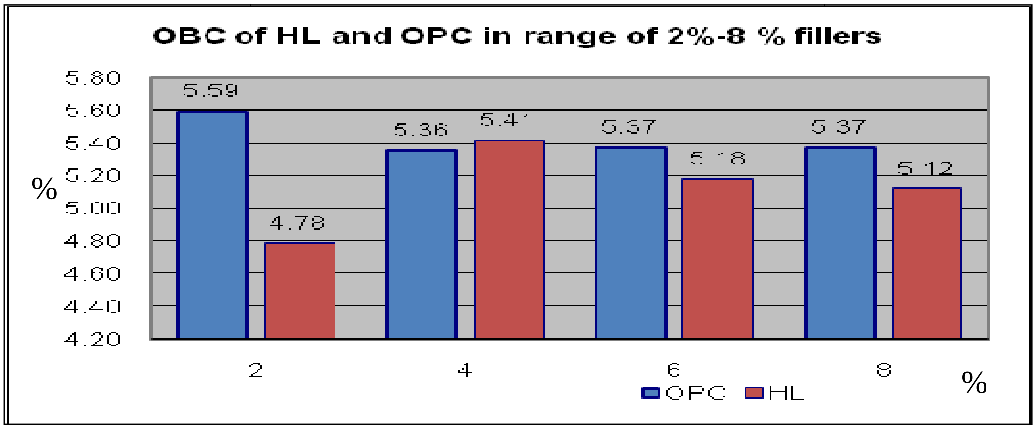

Figure 4.17 OBC result of 2%-8% fillers

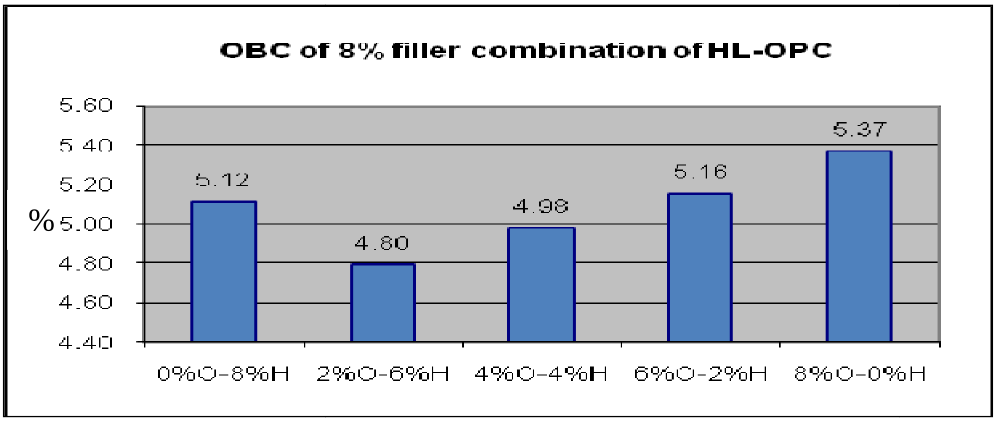

Figure 4.18 OBC result of mixtures combination of 8% filler

Figure 4.17 shows the OBC results from 2% - 8% filler content for both HL and OPC fillers. Figure 4.18 shows the OBC results for filler content combination fixed at 8%. The asphaltic concrete mixtures containing HL shows OBC increasing from 2% of HL content to 4% of HL content. Beyond 4 % of HL content, the OBC starts to decrease with increasing HL. This indicates that the OBC for HL mixtures occurred at 5.41% bitumen content. OPC mixtures containing 2% OPC exhibited the highest OBC at 5.59%. Further increase on OPC content resulted in the mixtures having lower OBC. The OBC for OPC mixtures therefore occurred for the 2% OPC content at 5.59% bitumen content. In other words, the optimum bitumen content for OPC mixtures is higher than that of HL mixtures (5.59% vs 5.41%). However this occurred at a lower OPC content in OPC mixtures (2% OPC vs 4% HL). In mixtures incorporating HL-OPC combinations, the OBC started to reduce from an initial 0% OPC filler content before increasing up to 8% OPC. The result of additional filler in the same percentage showed that additional percentage of OPC will increase the OBC. While additional percentage of HL filler will reduce the OBC. Moreover, based on the results showed in Table 4.3, mixtures containing 4% HL filler has the highest OBC value among other mixtures containing HL. They also showed better either in air voids than mixtures containing 2% OPC which has the highest OBC value among other mixtures containing OPC. Mixtures containing 4% HL showed more stiffness than mixtures containing 2% OPC. Also, the OBC requirement in mixtures containing 4% HL is lesser than mixtures containing 2% OPC; even if the stability value was lower.

Table 4.3 Parameters Value in OBC

NO	Type of Mixtures	OBC	Parameters value in OBC						
			Density	AV	VMA	VFA	Stability	Flow	Stiffness
I	OPC								
1	2%	5.59	2.43	4.97	18.48	72.14	15.16	3.40	4.28
2	4%	5.36	2.41	6.50	18.90	65.55	12.63	1.95	7.15
3	6%	5.37	2.45	5.23	17.86	70.42	13.10	4.14	3.39
4	8%	5.37	2.47	4.54	17.29	73.02	13.07	4.63	3.28
II	HL								
1	2%	4.78	2.41	7.02	18.05	63.61	14.68	2.70	5.37
2	4%	5.41	2.41	5.83	18.35	67.98	14.96	2.63	6.03
3	6%	5.18	2.40	6.35	18.31	65.20	12.31	5.18	2.44
4	8%	5.12	2.38	7.04	18.78	62.44	12.20	5.87	2.13
III	Combination of 8% filler								
1	0%OPC-8%HL	5.12	2.38	7.04	18.78	62.44	12.20	5.87	2.13
2	2%OPC-6%HL	4.80	2.42	6.83	17.97	61.93	15.17	4.29	3.74
3	4%OPC-4%HL	4.98	2.41	6.67	18.26	63.48	16.27	2.80	5.47
4	6%OPC-2%HL	5.16	2.40	7.40	19.27	61.81	13.96	3.79	3.77
5	8%OPC-0%HL	5.37	2.47	4.54	17.29	73.02	13.07	4.63	3.28

4.5 Mixture Performance on Permanent Deformation

One of the distresses in flexible pavement is permanent deformation. This occurs when a flexible pavement is inadequate to withstand plastic movement either caused by load or improper compaction during the construction. It can manifest itself in the form of rut depths in the pavement. It is thus necessary to analyze the factors that contribute to the resistance of pavement to permanent deformation. Two types of permanent deformation tests were applied to study the resistance of asphaltic concrete mixtures containing both OPC and HL fillers, namely the Dynamic Creep Test and the Wheel Tracking Test.

4.5.1 **Dynamic Creep test**

One of the simplest tests employed to measure permanent deformation of asphaltic mixtures is the creep test. There are two types of creep tests namely the static creep test and the dynamic creep test. In this study, the dynamic creep test was used to asses the ability of asphaltic mixtures to resist permanent deformation. This test also represents the near actual condition of pavement when passed by traffic. The static creep test simulates more the conditioning pavement when subjected to static loaded in parking areas. This test involved to use of cylindrical specimens similar to that in Marshall Test. The specimens were compacted with the gyratory compactor with bitumen content that has been derived from calculations OBC. For each OBC, three specimens were prepared. The dynamic creep tests were conducted in the UTM chamber at 40^{o}C. The creep test results are shown graphically in Figure 4.19 and Figure 4.20 for different filler content and for different filler combination respectively. Figure 4.21 and Figure 4.22 show the creep test results in the form of bar charts. For different filler content is shown by Figure 4.21 and for different filler combination is shown by Figure 4.22.

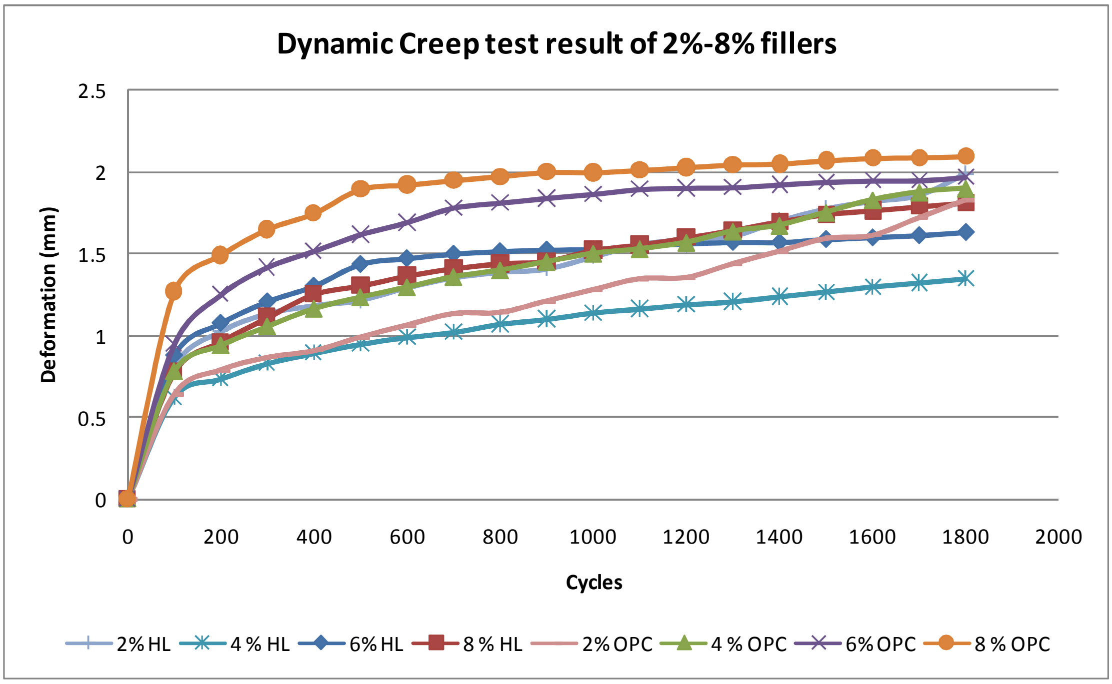

Figure 4.19 Dynamic Creep test result of 2%-8% fillers

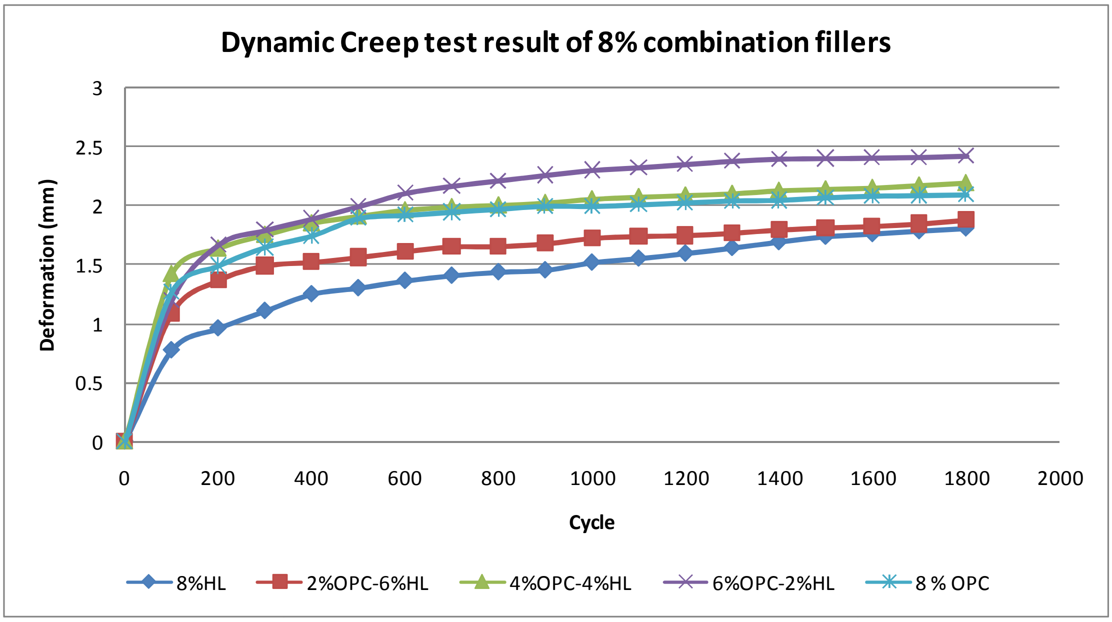

Figure 4.20 Dynamic Creep test result of mixtures combination of 8% filler

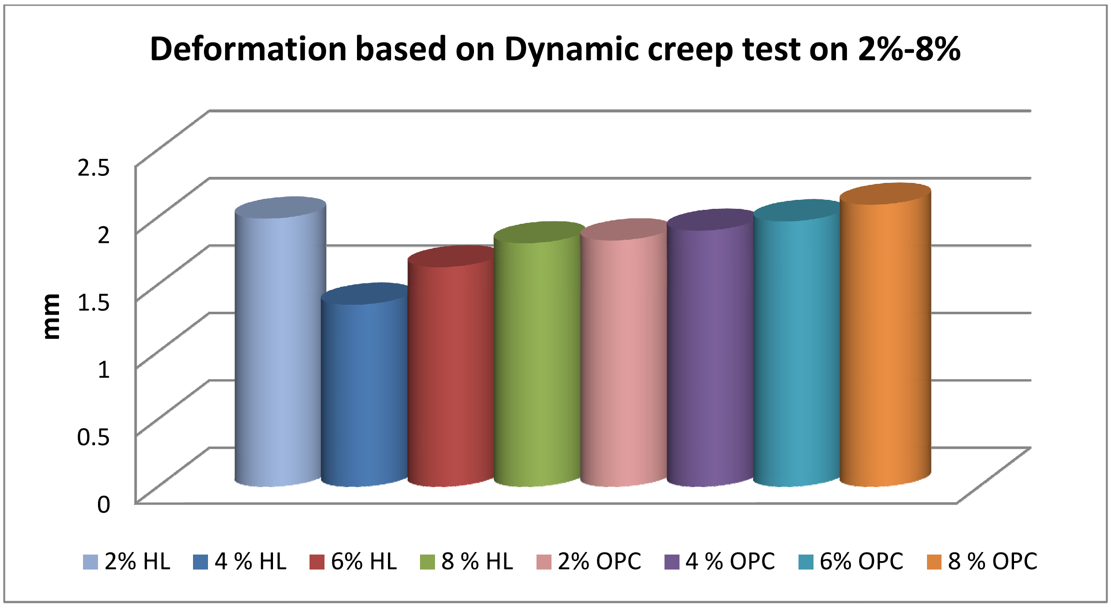

Figure 4.21 Dynamic Creep test chart of 2%-8% fillers

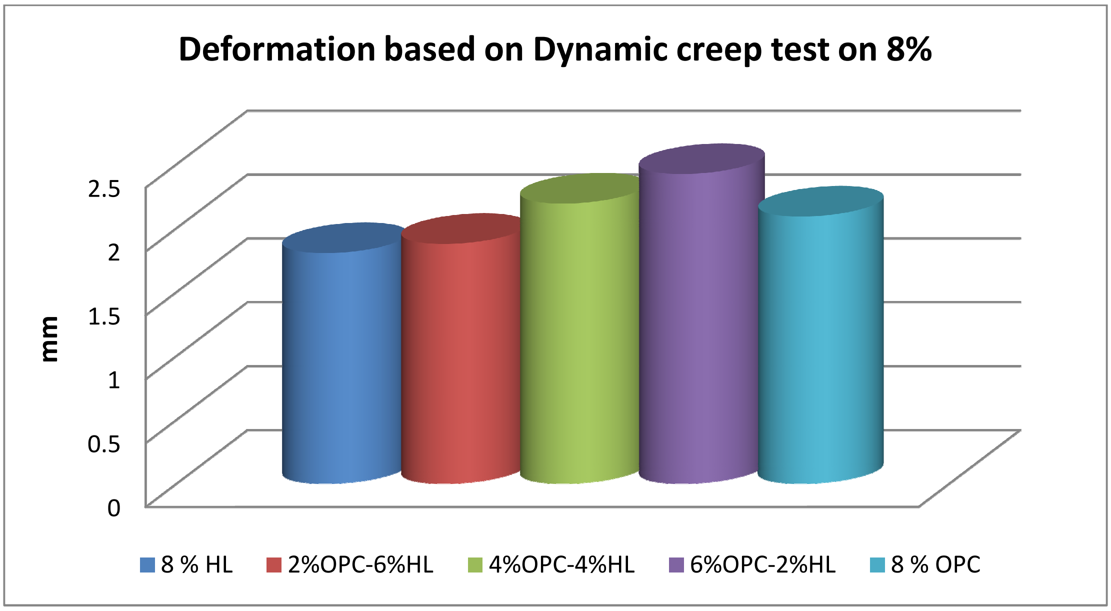

Figure 4.22 Dynamic Creep test chart of mixtures combination of 8% filler

The results showed that for the same percentage of filler content, after 1800 cycles of loading, the asphaltic mixtures containing HL exhibited lower permanent deformation than mixtures containing OPC; however, the mixtures containing 2% HL were an exception. As the filler content is increased, the material showed lower ability to resist rutting. It can be observed also from the line diagram as shown in Figure 4.19; in initial cycle of loading (0-200 cycle), mixtures containing HL has lower slope inclination deformation line than the mixtures containing OPC filler. After 200 cycles of loading, mixtures containing HL tend to have steady slope inclination than mixtures containing OPC filler. It can be seen especially by taking a look at bituminous mixtures containing 4%HL, 6%HL, 2% OPC, and 4% OPC. Bituminous mixtures containing OPC filler tend to fluctuate.

These phenomena can be explained based on the XRD, XRF and SEM tests. As can be seen from these tests, the particle size of HL is smaller than that of the OPC. In addition the strength of each particle of HL is higher than that of OPC. Furthermore HL exhibited irregular shape as compared to OPC particles which have oval shape. Irregular particle shape tends to have good interlocking between particles inside the mixtures, thus enhancing the resistance from deformation. HL filler which has lower specific gravity than OPC filler resulting greater particle amount in the same percentage of filler by weight. The higher particle amount inside the mixture will influence the characteristic of bitumen when mixed. It increases the viscosity of the bitumen making it inert. These characteristics contribute to the strength of the asphaltic mixture to resist from deformation. Previous studies on the effect of HL particles in bituminous mixtures [9] [11] showed that hydrated lime can tie up the carboxylic acids and 2-quinolones in the bitumen with the formation of insoluble calcium organic salts. This process prevents these functionalities from reacting with a siliceous surface to form water-sensitive bonds. This phenomenon leaves important active sites on the siliceous surface to form strong water-resistant bonds with nitrogen groups in the bitumen. As a result, asphaltic concrete mixtures incorporating HL fillers showed greater bitumen aggregate adhesion. Thus, even though the mixtures containing HL filler exhibited higher air void value, it still showed better resistance from deformation than the mixtures containing OPC filler.

For asphaltic concrete mixture containing filler incorporated both filler showed that a mixture containing 8% HL had the lowest value in the deformation test. It then starts to increase until the presence of OPC reaches 6%, then decrease again when all fillers are replaced by the OPC filler. It still has, however, higher rut depth than HL mixtures. It can be understood that the particle size and particle shape of both filler have contribution to this phenomenon. The addition of OPC filler percentage can reduce the presence of HL filler. Thus, it reduces the particle that has either irregular shape or stronger particle inside the mixtures. Nevertheless, all analyses above should be subjected to the wheel tracking test. For further verification, based on the T-Test analysis as seen in Appendix B and Appendix C, eventhough there were different deformation result, basically based on the T-Test result, changing both fillers in asphaltic mixtures did not make any significant result in deformation. This could be caused by the lack specimen amount during the test, which only used three (3) specimens of each filler percentage.

4.5.2 **Wheel tracking test**

The Wheel Tracking test is another test used to analyze the ability of pavement materials to resist rutting. An actual wheel loading with a 520 N load is applied in this test to the asphaltic mixtures slab specimen having dimensions of 305 mm (L) x 305 mm (W) x 50 mm (H). The temperature of test is set at 40^{o}C.The results are shown by the total rut depth obtained after 42 wheel passes/minute for 45 minutes loading. The wheel tracking test results are exhibited in Figure 4.23 until Figure 4.26. Figure 4.23

shows the wheel tracking test result for different filler content and Figure 4.24 shows the wheel tracking test result for different filler combination in the form of line diagram. These diagrams exhibited the inclination of the graph for different filler content. From these graph can be measured the wheel tracking rate for different filler content. The result of the wheel tracking rate is shown in Table 4.4 and Table 4.5 for different filler content and for different filler combination respectively. Figure 4.25 shows the wheel tracking test result for different filler content and Figure 4.26 shows the wheel tracking test result for different filler combination in the form of bar charts. These bar charts exhibited the end results of the deformation test for different filler content.

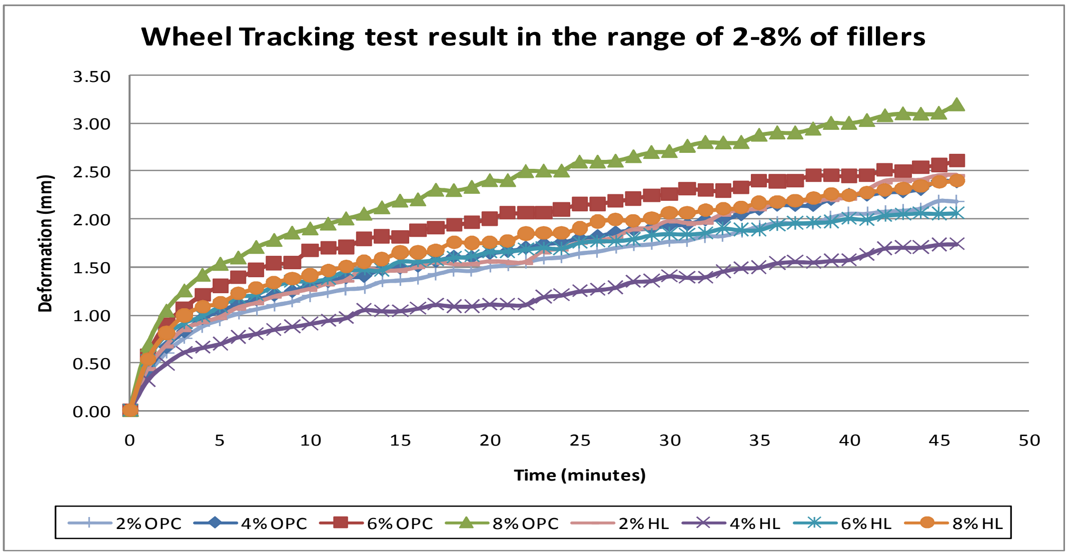

Figure 4.23 Wheel Tracking test result of 2%-8% fillers

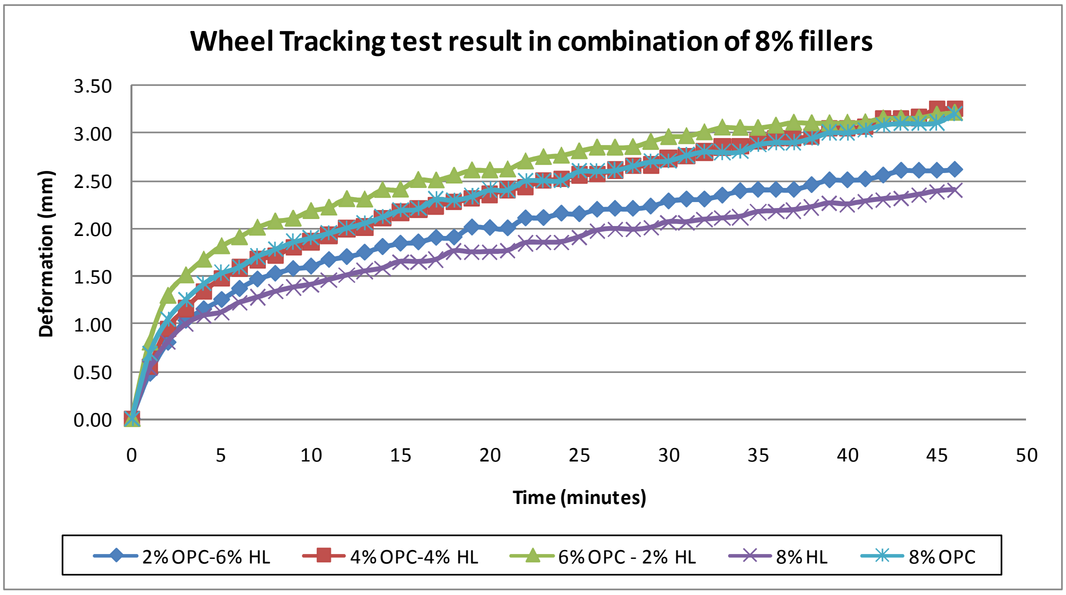

Figure 4.24 Wheel Tracking test result of mixtures combination of 8% filler

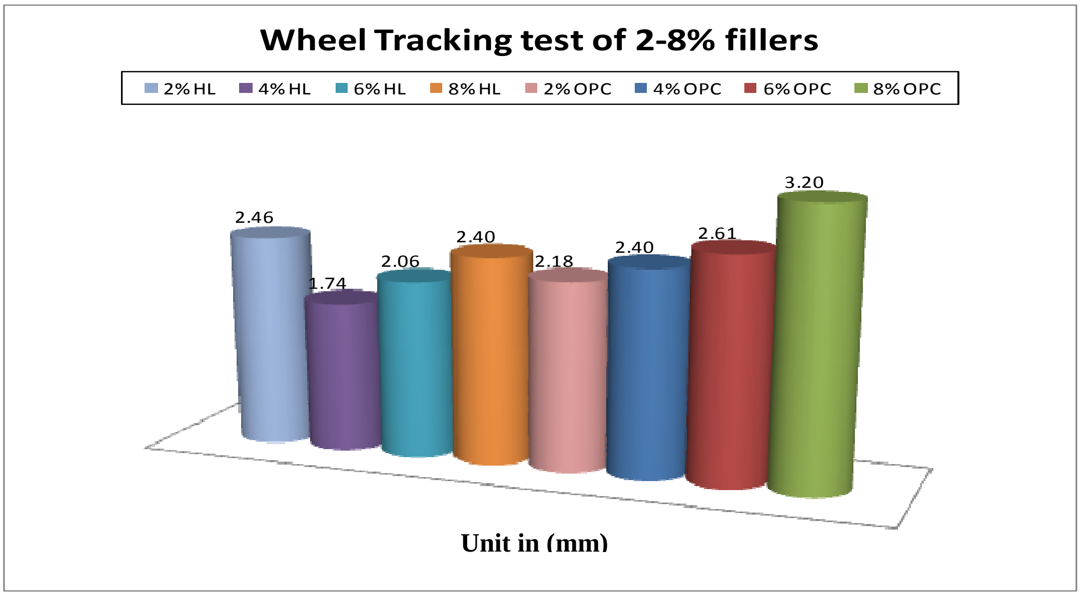

Figure 4.25 Wheel Tracking test chart of 2%-8% fillers

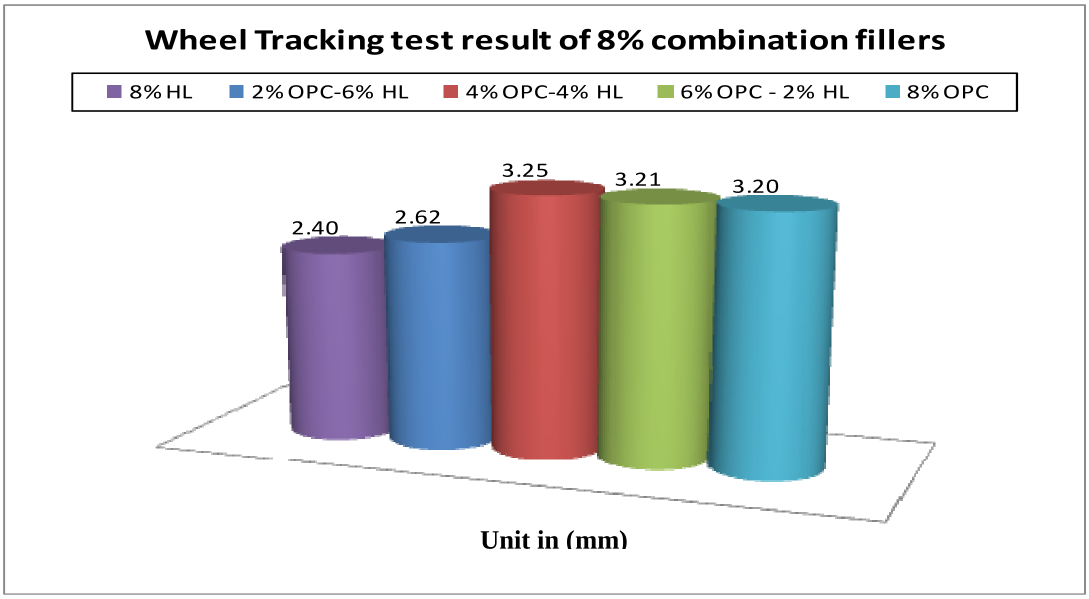

Figure 4.26 Wheel Tracking test chart of mixtures combination of 8% filler

The results of the Wheel Tracking Test showed similar trends as the dynamic creep test result. The asphaltic mixtures containing HL exhibited lower permanent deformation than mixtures containing OPC; however, the mixtures containing 2% HL were an exception. This phenomenon can be explained based on the XRD, XRF, SEM and Specific Gravity tests. From these tests, it can be concluded that HL particle has several over plus than OPC particle. HL has irregular particle shape which tends to have good interlocking between particles inside the mixtures thus enhancing the resistance from deformation. HL also has either smaller or harder particle which influence the bituminous mixtures to resist from deformation. HL filler also has lower specific gravity than OPC filler, resulting greater particle amount in the same percentage of filler by weight. The higher particle amount inside the mixture increases the viscosity of the bitumen, making it inert, thus resist from deformation.

The filler percentage addition reduces the resistance of AC mixtures from deformation. It occurs because the filler percentage addition increases the surface area that must be covered by the bitumen. It reduces the asphalt thin film thickness that diminishes asphaltic concrete mixture performance. For the mixtures containing 8% combination of both fillers has shown that the addition of OPC filler percentage increases the deformation. These trends can be correlated to the result of XR-D test and SEM test. HL particle has irregular particle shape than OPC which has oval shape. Addition of the OPC filler percentage reduces the presence of HL particle, thus, reducing irregular particles inside the bituminous mixture. Besides, based on the XR-D test, HL has stronger particle than OPC. Replacing HL filler with OPC filler reduces the presence of stronger filler inside bituminous mixture, thus reducing the resistance of bituminous mixture from permanent deformation.

Another way to assess the performance of bituminous mixture in the wheel tracking test can be analyzed using the wheel tracking rate. This concept has been introduced by Choyce et al. The assessment is obtained by taking a look to the main rate of rut depth in 30 minutes and 45 minutes [78]. Overall, the wheel tracking rate of the asphaltic concrete mixtures containing HL filler have showed less deformation than the mixtures containing OPC; however, the mixtures containing 2% HL were an exception. This is evidenced by Niazi et.al that compared OPC and HL as filler in cold in place recycling mix in 2% filler content. The result showed that OPC has less deformation than HL in 2% filler content [10]. Apparently HL plays good contribution in resistance from permanent deformation in the 4% filler content. The wheel tracking rates are shown in Table 4.4 and Table 4.5 for different filler content and for different filler combination respectively.

Table 4.4 Deformation rate per minute of 2%-8% filler

WHEEL TRACKING RATE (mm/hr)

OPC				HL			
2%	4%	6%	8%	2%	4%	6%	8%
1.69	1.86	1.22	1.60	1.90	1.32	0.84	1.28

Table 4.5 Deformation rate per minute of mixtures combination of 8% filler

WHEEL TRACKING RATE (mm/hr)

8HL-0OPC	6HL-2OPC	4HL-4OPC	2HL-6OPC	0HL-8OPC
1.28	1.28	2.06	0.94	1.60

4.6 Mixture Performance on Fatigue

Fatigue can be defined as a fracture phenomenon under maximum repeated or fluctuating stress that is less than the tensile strength of the material [2]. Fatigue in asphaltic mixtures is the phenomenon of cracking that consist of two main phases, i.e.

crack initiation and crack propagation. The asphaltic mixtures resistance to fatigue distress depends on its tensile strength.

The three point beam bending fatigue test was used in this study to determine the asphaltic mixture resistance to fatigue distress. The control strain mode was used in this study. Consequently, the results of the beam fatigue test are shown in the function of stress versus load cycles.

The results are presented in Figure 4.27 and Figure 4.28. Figure 4.27 shows the beam fatigue result for the mixtures containing different filler content and Figure 4.28 shows the beam fatigue result for mixtures containing different filler combination. The graph trend line was expressed as logarithmic, and the general equation is formed as,

$$y = -a \ln(x) + b \qquad \text{4-1}$$

or

$$\sigma = -a \ln(N) + b \qquad \text{4-2}$$

where;

$y = \sigma$ = stress

$x = N$ = cycle

a = equation gradient/slope factor

b = constant

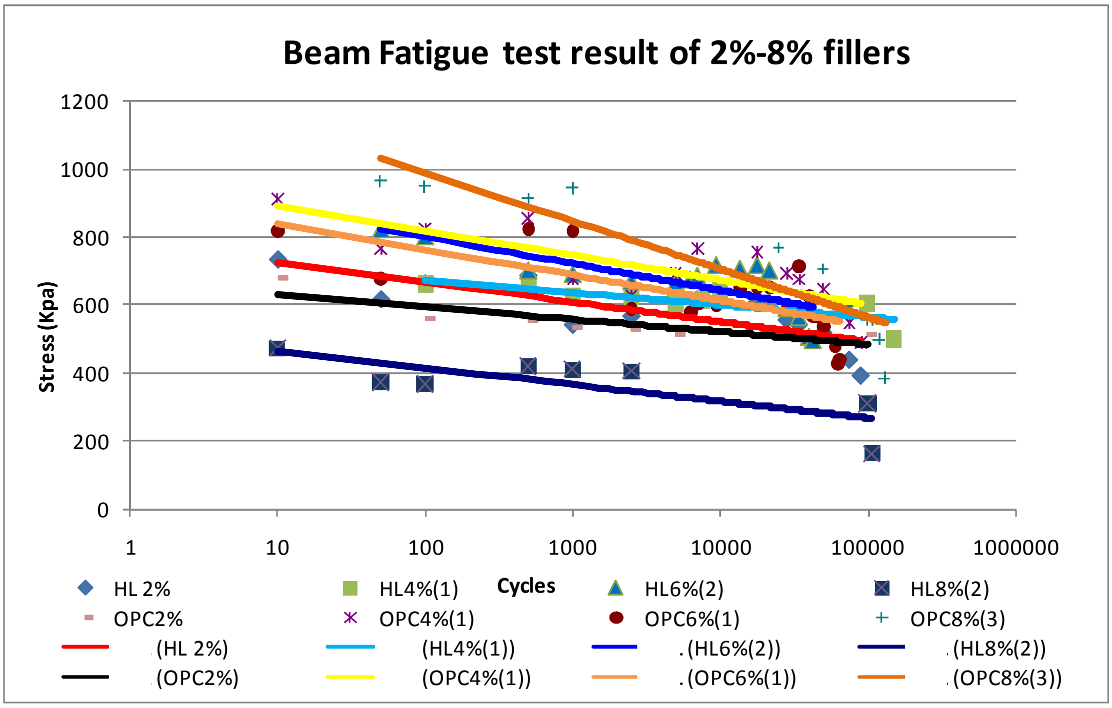

Figure 4.27 Beam Fatigue test result of 2%-8% fillers

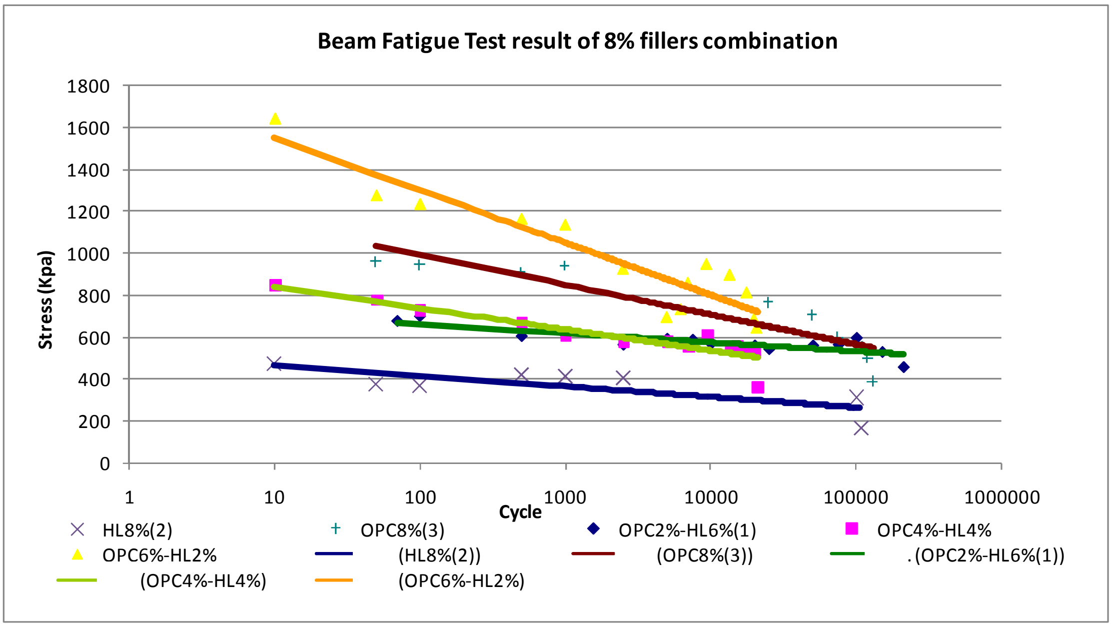

Figure 4.28 Beam Fatigue test result of mixtures combination of 8% filler

The results are analyzed by taking a look at the inclination of the graph line. The results show that the asphaltic mixtures containing 4% HL has the lowest line slope inclination. This means that in the same percentage of filler, mixture containing 4% HL has better fatigue resistance than other mixtures. This can be explained from the mechanical and chemical properties. HL has smaller, stronger, and also irregular shape in particle than OPC. Besides, HL in asphaltic concrete mixtures has the ability in micro damage healing, especially in low temperature [13] [79]. Nevertheless, the highest stiffness in initial cycles is achieved by the asphaltic mixtures containing 8% OPC filler. However in the end of cycles, the stiffness is lower than the mixture containing 4% HL filler. This phenomenon occurs because of in the initial condition, higher OPC particle amount increase the density of the mixture producing stiffer mixture. However at the end of cycle, the excess of the OPC particle amount increase the surface area of particle that must be covered. It produces lower performance in fatigue resistance. The lowest result of the fatigue test is obtained by mixture containing 8% HL. This happened because of mixture containing 8% HL is the mixture which has the most excess filler among other. The excess particles of HL filler reduce the asphalt film thickness, raising brittle phenomenon.

In incorporating mixtures containing both fillers as shown Figure 4.28 shows that the lowest slope inclination is achieved by mixtures containing 2% OPC - 6% HL. It means this composition is the best mixtures containing combination of both filler that resist from fatigue distress. This is caused by the presence of both filler in the mixtures making good interlocking inside the bituminous mixture. HL fillers which have smaller particle size than OPC fillers fill the pores that can’t be entered by the OPC filler. Besides, HL has effect to change the chemical properties of the bitumen which enhancing the viscosity of the bitumen. HL also increases the aggregate bitumen adhesion, thus, enhancing the resistance of bituminous mixture from fatigue distress.

4.7 Summary

After analyzing the effects of both fillers either HL or OPC in asphaltic concrete mixtures, it is necessary to optimize the best overall mixture performance. Because of the highest result of asphaltic mixtures permanent deformation test such as wheel tracking test and dynamic creep test tend to weaken in fatigue test and vice versa. Thus, both criteria in the experimental results obtained in this work were compared in order to determine the optimum composition of bituminous mixtures for different fillers. The bituminous mixtures were assessed from 3 different aspects of mixture parameters i.e. engineering properties, permanent deformation and fatigue performance, by ranking all the mixtures according to their performance under each category of mixture parameter. The mixtures are ranked from 1 (as the most desired characteristic) to 13 (as the least desired characteristic). Rank 1 is given to the mixtures with the high value of density, stability and stiffness and low values of VMA and OBC. As for mixture performance, ranking 1 is given to the mixture with the lowest permanent deformation which was obtained from the wheel tracking test and the lowest slope as defined by the relationships of stress and cycles to failure in the fatigue tests. The ranking of all the mixtures were then summarized and tabulated in Table 4.6.

Table 4.6 Mixtures Rank

NO	TYPE OF MIXTURES	ENGINEERING PROPERTIES	PERMANENT DEFORMATION		FATIGUE DISTRESS	MIXTURES RANK
			DCT	WTT		
1	2 % HL	2	7	6	6	6
2	4 % HL	5	1	1	1	1
3	6% HL	7	2	2	4	2
4	8 % HL	8	3	5	8	8
5	2% OPC	4	4	3	7	3
6	4% OPC	6	5	4	3	4
7	6% OPC	3	6	7	5	7
8	8% OPC	1	9	8	2	5
9	0%OPC-8%HL	3	1	1	3	2
10	2%OPC-6%HL	2	2	2	1	1
11	4%OPC-4%HL	1	4	5	4	4
12	6%OPC-2%HL	4	5	4	5	5
13	8%OPC-0%HL	5	3	3	2	3

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This research compared the effect of Hydrated Lime (HL) and Ordinary Portland Cement (OPC) as fillers in asphalt concrete pavement. Several mixtures of Asphaltic Concrete with various proportions of filler have been evaluated using several performance tests to reveal the resistance to either permanent deformation and fatigue distresses. Chemical analyses of both filler were also conducted using XRF, XRD and SEM test. Based on the laboratory results obtained, the following conclusions can be made:

1. Based on the XRF test result, HL particle has better chemical bonding than OPC particle. When used in asphaltic concrete mixtures, it is expected to enhance the chemical and mechanical properties of asphaltic concrete mixtures.

2. Referring to the SEM results for the same magnification, HL has smaller particle size than OPC. It can thus better fill the asphalt concrete mixture pores. Besides, HL has an irregular shape leading to good interlocking inside the mixtures. This is contrast with OPC particles which have spherical shape.

3. Based on the XR-Diffraction result, HL has higher Ln value than OPC. This implies that HL particles are stronger than the OPC particles when used in asphaltic concrete mixtures.

4. For the same percentage of filler content, it was found that HL has a higher stability value than OPC owing to the smaller size of the HL particles in contrast to the OPC particles.

5. The Wheel Tracking Test samples have shown similar trend with stability value result. For the same percentage of filler, bituminous mixtures containing HL filler shows greater resistance to deformation than mixtures containing OPC

6. The effect of both fillers based on the Dynamic Creep Test result also show the same phenomenon as the results obtained by the Wheel Tracking Test. Asphalt Concrete Mixtures containing HL provide greater resistance to permanent deformation than asphalt mixtures containing OPC.

7. Based on the Beam Fatigue Test result, asphaltic concrete mixtures containing HL have lower slope inclination than asphaltic concrete mixtures containing OPC. This is proof that HL mixtures are more durable to fatigue distress than OPC mixtures. This is especially showed in mixtures containing 4% HL fillers as shown in this study.

5.2 Recommendation

In light of the findings and conclusions of this study, the author recommends the following:

1. In order to study the effect of OPC and HL as filler in asphaltic concrete mixtures to tensile fatigue, it is suggested that further studies be carried out to investigate this using the Indirect Tensile Fatigue test.

2. Many literatures have stated that HL and OPC filler have ability as an anti-stripping agent. It is therefore necessary to study this property for both fillers. Stripping test, such as the Immersion Wheel Tracking test should be conducted.

3. To know the effect of OPC and HL filler in bitumen hardening, it is suggested to carry out test using ageing test such as The Rolling Thin-Film Oven Test (RTFOT).

APPENDIX A

Optimum Bitumen Content of Asphaltic Mixtures containing HL

HL	OBC			
%	2	4	6	8
STABILITY	**5.52**	5.27	4.43	3.90
DENSITY	**3.00**	5.27	5.20	5.30
VMA	**4.88**	4.88	4.73	4.86
VFA	**5.73**	6.23	6.36	6.42
AVERAGE	**4.78**	**5.41**	**5.18**	**5.12**

Optimum Bitumen Content of Asphaltic Mixtures containing OPC

OPC	OBC			
%	2	4	6	8
STABILITY	5.20	5.42	5.11	5.08
DENSITY	5.63	4.99	5.30	5.36
VMA	5.16	4.11	4.97	5.15
VFA	6.37	6.90	6.10	5.90
AVERAGE	**5.59**	**5.36**	**5.37**	**5.37**

Optimum Bitumen Content of Asphaltic Mixtures containing incorporated of both fillers (OPC-HL)

HL	OBC				
%	0%O-8%H	2%O-6%H	4%O-4%H	6%O-2%H	8%O-0%H
STABILITY	**3.90**	4.56	4.38	4.57	**5.08**
DENSITY	**5.30**	4.68	5.01	5.15	**5.36**
VMA	**4.86**	3.92	4.64	4.58	**5.15**
VFA	**6.42**	6.04	5.90	6.35	**5.90**
AVERAGE	**5.12**	**4.80**	**4.98**	**5.16**	**5.37**

‘

T-Test results of OBC

T-Test: Two-Sample Assuming Unequal Variances
Alpha: 0.05
H_0: $\mu_1 = \mu_2$
H_1: $\mu_1 \neq \mu_2$
If t stat < t critical one-tail □ H_0 (the difference is not significant)
If t stat $\geq$ t critical one-tail □ H_1 (the difference is significant)

HL

% of Fillers	*2*	*4*	*2*	*6*	*2*	*8*
Mean	4.783	5.411	4.783	5.179	4.783	5.119
Variance	1.546	0.333	1.546	0.724	1.546	1.093
Observations	4	4	4	4	4	4
Hypothesized Mean Difference	0		0		0	
df	4		5		6	
t Stat	-0.916		-0.526		-0.414	
P(T<=t) one-tail	0.206		0.311		0.347	
t Critical one-tail	2.132		2.015		1.943	
P(T<=t) two-tail	0.411		0.621		0.693	
t Critical two-tail	2.776		2.571		2.447	

OPC

% of Fillers	*2*	*4*	*2*	*6*	*2*	*8*
Mean	5.591	5.355	5.591	5.370	5.591	5.372
Variance	0.317	1.360	0.317	0.252	0.317	0.140
Observations	4	4	4	4	4	4
Hypothesized Mean Difference	0		0		0	
df	4		6		5	
t Stat	0.364		0.585		0.649	
P(T<=t) one-tail	0.367		0.290		0.272	
t Critical one-tail	2.132		1.943		2.015	
P(T<=t) two-tail	0.734		0.580		0.545	
t Critical two-tail	2.776		2.447		2.571	

OPC vs HL

% of Fillers	*2OPC*	*2HL*	*4OPC*	*4HL*	*6OPC*	*6HL*	*8OPC*	*8HL*
Mean	5.591	4.783	5.355	5.411	5.370	5.179	5.372	5.119
Variance	0.317	1.546	1.360	0.333	0.252	0.724	0.140	1.093
Observations	4	4	4	4	4	4	4	4
Hypothesized Mean Difference	0		0		0		0	
df	4		4		5		4	
t Stat	1.184		-0.086		0.387		0.455	
P(T<=t) one-tail	0.151		0.468		0.358		0.337	
t Critical one-tail	2.132		2.132		2.015		2.132	
P(T<=t) two-tail	0.302		0.936		0.715		0.673	
t Critical two-tail	2.776		2.776		2.571		2.776	

INCORPORATING BOTH FILLER

% of Fillers	*0%O-8%H*	*2%O-6%H*	*0%O-8%H*	*4%O-4%H*	*0%O-8%H*	*6%O-2%H*	*0%O-8%H*	*8%O-0%H*
Mean	5.119	4.797	5.119	4.981	5.119	5.160	5.119	5.372
Variance	1.093	0.790	1.093	0.441	1.093	0.701	1.093	0.140
Observations	4	4	4	4	4	4	4	4
Hypothesized Mean Difference	0		0		0		0	
df	6		5		6		4	
t Stat	0.469		0.223		-0.061		-0.455	
P(T<=t) one-tail	0.328		0.416		0.477		0.337	
t Critical one-tail	1.943		2.015		1.943		2.132	
P(T<=t) two-tail	0.655		0.833		0.953		0.673	
t Critical two-tail	2.447		2.571		2.447		2.776	

APPENDIX B

The Deformation results from Wheel Tracking Test (mm)

[redacted]

%	0O-8HL	2O-6HL	4O-4HL	6O-2HL	8O-0HL
I	**2.66**	**2.52**	**2.70**	**2.81**	**2.90**
II	**2.14**	**2.71**	**3.80**	**3.61**	**3.50**
AVERAGE	2.40	2.62	3.25	3.21	3.20

T-Test: Two-Sample Assuming Unequal Variances
Alpha: 0.05
H_0: $\mu_1 = \mu_2$
H_1: $\mu_1 \neq \mu_2$
If t stat < t critical one-tail □ H_0 (the difference is not significant)
If t stat ≥ t critical one-tail □ H_1 (the difference is significant)

T-Test results for Wheel Tracking Test

HL

% of Filler	***2***	***4***	***2***	***6***	***2***	***8***
Mean	2.458	1.740	2.458	2.060	2.458	2.400
Variance	0.333	0.088	0.333	0.020	0.333	0.135
Observations	2	2	2	2	2	2
Hypothesized Mean Difference	0		0		0	
df	1		1		2	
t Stat	1.565		0.948		0.121	
P(T<=t) one-tail	0.181		0.259		0.458	
t Critical one-tail	6.314		6.314		2.920	
P(T<=t) two-tail	0.362		0.517		0.915	
t Critical two-tail	12.706		12.706		4.303	

OPC

% of Filler	***2***	***4***	***2***	***6***	***2***	***8***
Mean	2.184	2.395	2.184	2.610	2.184	3.200
Variance	0.030	0.042	0.030	0.045	0.030	0.180
Observations	2	2	2	2	2	2
Hypothesized Mean Difference	0		0		0	
df	2		2		1	
t Stat	-1.113		-2.200		-3.136	
P(T<=t) one-tail	0.191		0.079		0.098	
t Critical one-tail	2.920		2.920		6.314	
P(T<=t) two-tail	0.382		0.159		0.197	
t Critical two-tail	4.303		4.303		12.706	

OPC vs HL

% of Filler	*2OPC*	*2HL*	*4OPC*	*4HL*	*6OPC*	*6HL*	*8OPC*	*8HL*
Mean	2.184	2.458	2.395	1.740	2.610	2.060	3.200	2.400
Variance	0.030	0.333	0.042	0.088	0.045	0.020	0.180	0.135
Observations	2	2	2	2	2	2	2	2
Hypothesized Mean Difference	0		0		0		0	
df	1		2		2		2	
t Stat	-0.645		2.567		3.051		2.015	
P(T<=t) one-tail	0.318		0.062		0.046		0.091	
t Critical one-tail	6.314		2.920		2.920		2.920	
P(T<=t) two-tail	0.636		0.124		0.093		0.181	
t Critical two-tail	12.706		4.303		4.303		4.303	

INCORPORATING BOTH FILLER

% of Filler	*0O-8HL*	*2O-6HL*	*0O-8HL*	*4O-4HL*	*0O-8HL*	*6O-2HL*	*0O-8HL*	*8O-0HL*
Mean	2.400	2.615	2.400	3.250	2.400	3.210	2.400	3.200
Variance	0.135	0.018	0.135	0.605	0.135	0.320	0.135	0.180
Observations	2	2	2	2	2	2	2	2
Hypothesized Mean Difference	0		0		0		0	
df	1		1		2		2	
t Stat	-0.777		-1.397		-1.698		-2.015	
P(T<=t) one-tail	0.290		0.198		0.116		0.091	
t Critical one-tail	6.314		6.314		2.920		2.920	
P(T<=t) two-tail	0.580		0.395		0.232		0.181	
t Critical two-tail	12.706		12.706		4.303		4.303	

APPENDIX C

The Deformation results from Dynamic Creep Test (mm)

[redacted]

[redacted]

T-Test: Two-Sample Assuming Unequal Variances
Alpha: 0.05
H_0: $\mu_1 = \mu_2$
H_1: $\mu_1 \neq \mu_2$
If t stat < t critical one-tail H_0 (the difference is not significant)
If t stat ≥ t critical one-tail H_1 (the difference is significant)

T-Test results for Dynamic Creep Test

[redacted]

[redacted]

APPENDIX D

Mixtures Rank

%	0%O-8%H	2%O-6%H	4%O-4%H	6%O-2%H	8%O-0%H
STABILITY	4	2	1	3	5
DENSITY	4	1	2	3	4
AV	2	4	1	5	3
VMA	3	1	2	5	4
STIFFNESS	5	3	1	2	4
OBC	3	1	2	4	5
SUM	16	9	8	20	21
RANK	3	2	1	4	5

FILLER	HL				OPC			
%	**2**	**4**	**6**	**8**	**2**	**4**	**6**	**8**
STABILITY	**1**	**3**	**7**	**4**	**2**	**8**	**6**	**5**
DENSITY	**8**	**5**	**6**	**7**	**3**	**4**	**2**	**1**
AV	**5**	**4**	**6**	**8**	**2**	**7**	**3**	**1**
VMA	**3**	**4**	**5**	**8**	**7**	**6**	**2**	**1**
STIFFNESS	**4**	**3**	**8**	**7**	**2**	**1**	**6**	**5**
OBC	**1**	**7**	**3**	**2**	**8**	**4**	**5**	**6**
SUM	**22**	**26**	**35**	**36**	**24**	**30**	**24**	**19**
RANK	**2**	**5**	**7**	**8**	**4**	**6**	**3**	**1**

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