Bituminous Mixtures Properties Using Different Aggregate Types

by

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14173

Dissertation submitted in partial fulfilment of
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CERTIFICATION OF APPROVAL

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September 2014

CERTIFICATION OF ORIGINALITY

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

Yonas Balcha Mecha

ABSTRACT

Mineral aggregate constitutes approximately 95% of hot-mix asphalt by weight. Thus, it contributes a lot to the characteristic of bituminous mixtures. For materials of such importance, there is a literature gap on the properties of aggregates obtained from primary sources of aggregates in Malaysia – rock quarries. This study is to determine bituminous mixture properties using aggregates from four different quarries which are Mukim Sungai Raya, Kampar, Lahat and Kampung Keramat Pulai, and their suitability to use them in Malaysian road construction. Los Angeles abrasion value, aggregate impact, water absorption capacity and specific gravity tests were conducted to determine the mechanical and physical properties of the aggregates. Then the percentage of voids in total mix, voids in mineral aggregates, specific gravity, Marshal Stability and flow of the bituminous mix sample prepared from each quarry were determined. The results were analysed by comparing the stability, flow and percentage of voids in total mix to the Jabatan Kerja Raya (JKR) standards. The properties of the aggregates were also compared to the JKR requirements. The results showed that aggregates from Kamput Keramat Pulai satisfy all the JKR (Malaysian Pavement Design Manual) specifications.

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CHAPTER 1: INTRODUCTION

1.1 Background of study

Bituminous mixture is a composite material commonly used in construction projects such as road surfaces, airports and parking lots. In order to determine bituminous mixture properties, one must understand basic properties of the individual components that comprise the mixture. The components are aggregates (coarse and fine aggregates), bitumen or bitumen-based binder and fillers. Of these components, aggregates play an important role as it accounts for 95 percent of the mixture by weight or 80 percent by volume [1].

Aggregates are a major material for construction projects. Production of aggregates for building construction and other civil engineering works is one of the world's major industries. Aggregates are mainly used for construction purposes such as making concrete mix, paving blocks, partition blocks, railway ballast, road and airport surfacing materials. The aggregates are inert (that is, chemically inactive) materials mixed with a binding material like cement, lime or mud in the preparation of mortar or concrete. The Geological Society, London (1993) defined aggregates as the particles of rock which when brought together in a bound and unbound condition form part or whole of an engineering or building structure [2]. Rocks have been used as a construction material in various ways. Rocks like granite, diorite, andesite, dolerite, limestone, greywacke, gneiss, quartzite etc. are used as aggregates in different parts of the world. The choice depends either on the purpose of use or on the availability of the type of rock within the vicinity of use.

Aggregates have certain properties that withstand the stress imposed in road surfaces and sub-surface layers which make them a fundamental constituent of a bituminous mixtures [3]. The main properties are mechanical properties, physical properties, thermal and weathering properties, and chemical properties of aggregates. Laboratory tests such as aggregate crushing value test, aggregate impact value test, aggregate abrasion value test, ten percent fine test and polished stone value tests are used to determine mechanical properties of aggregates. Aggregate gradation (size), aggregate shape (flakiness and elongation), specific gravity, absorption, porosity, permeability, aggregate voids and shell content of the aggregate comprises the main physical properties of the aggregate. Magnesium Sulphate soundness test is used to determine a weathering characteristic of an aggregate. Finally determination of Sulphate content, alkali-silica reactivity and petrographic examination make the main chemical tests for aggregate. These properties of aggregates are due to the constituent particles and the manner in which they are bound together [3]. Hence, different aggregates types have different properties.

One way to classify aggregates is based on their sources. Aggregates can be natural or artificial. Natural aggregates can be produced by excavation of naturally occurring rocks from quarries. Once the rock is excavated it is crushed in to smaller sizes and screened using different sieves. Another source of natural aggregates, as in gravel, is river banks or glacial deposits in which the aggregates are washed away from their original sources. Artificial aggregates consist of industrial by-products like slag - by product of metallurgical process (mainly steel, copper and tin). Different part of the world uses different types of aggregates. The selection of a specific types of aggregates is primarily based on the type of aggregate present in adjacent vicinity of the construction site as cost of moving aggregates is high.

Aggregate types affect the properties of bituminous mixture as different aggregates have different properties [4]. These bituminous mixtures properties include optimum bitumen content (OBC), Marshal Stability, bulk density, Marshal Stiffness, flow, air voids, and voids in mineral aggregates, voids filled with bitumen, bulk density, durability, workability and filler/binder ratio. Different types of aggregates differ with one another because they are constituted of different particles and the way the constituent particles arranged is different. These different aggregate have different properties that largely affect the bituminous mixture properties.

1.2 Problem Statement

In different part of the world different types of aggregates are used for road construction. However in Malaysia due to their vast availability granite and limestone are the most utilized crushed stone aggregates. Granite is the main crushed stone aggregate, with a contribution of 70 percent and followed by limestone making up 15percent of the crushed stone aggregates used; the rest of aggregates come from diorite, sandstone, basalt, andesite, dolomite and gabbro [5].

As it is more likely that in the future the sources of aggregates may become depleted, it's very important to assess different sources of aggregates with respect to their engineering properties. Usually the properties of aggregates are determined from a standard laboratory tests which shows the quality of the aggregates. The main principle behind aggregate selection is highest quality aggregate with least cost of production.

In Malaysia, rock quarries are the main sources of aggregates that are utilized for road construction. These quarries from which granite and limestone are the two mostly produced aggregates are found in different parts of Malaysia. Before the aggregates are used in the road construction, they have to meet the quality standards outlined in Jabatan Kerja Raya (JKR) – a manual in pavement design in Malaysia. Therefore, there is a need for conducting research on the suitability of different quarries as source of aggregates for Malaysian road construction.

In this particular project, the suitability of aggregates from Kampung Keramat Pulai, Kampar, Lahat and Mukim Sungai Raya quarries for road construction. The results obtained from this particular project can be a useful tool to easily evaluate whether the quarries in question can be used as a source of aggregate for road construction.

1.3 Objectives

The objectives of this project are:

i. To determine the physical and mechanical properties of the aggregates from the four quarries

ii. To determine whether the aggregates from the quarries meet JKR standards

1.4 Scope of the study

Although there are a lot of aggregate types that are used in the road construction sector all over the world, this particular study will cover aggregates primarily used in Malaysian road constructions. The project specifically will study the two most used aggregates in Malaysia - limestone and granite. It will focus on effect of limestone and granite aggregate bituminous mixtures. However, the study still covers a larger scope related to the components of bituminous mixtures. Two samples of aggregates, one containing limestone and the other containing granite will be prepared.

In the initial stage of the project researches will be done on limestone and granite aggregates from different quarries (Kampung Keramat Pulai, Kampar , Lahat and Mukim Sungai Raya) and their properties will be determined, bitumen properties and also on the properties of bituminous mixtures. Then the aggregates will be selected with the standard sampling techniques and aggregate gradation values stipulated in JKR (Jabatan Kerja Raya) – Malaysian Standard Specifications for Road Works. A bitumen of Penetration Grade of 80-100 will be prepared again using the specification in JKR.

Once the aggregates are prepared accordingly, laboratory tests will be done on both limestone and granite aggregates from all of the four quarries to determine the mechanical and physical properties of the aggregates according to ASTM and BS standards. These tests include specific gravity, water absorption, Los Angeles abrasion, aggregate impact value, polished stone value, ten percent fine, and elongation and flakiness tests. Lab tests will be done to determine the specific gravity of the filler as well. Lab tests such as ductility test, standard penetration test, softening point test, and specific gravity will also be done on the bitumen based on standards set out in JKR

Lab tests also will be done to determine the properties of bituminous mixtures using limestone and bituminous mixture using granite aggregates. The properties include the specific gravity, void, flow, stability, stiffness and density of the bituminous mixtures. All of these characteristics will be used to determine the best combination of bituminous mixtures.

CHAPETER 2. LITERATURE REVIEW

Bituminous mixtures are one of the main ingredients for the ever growing road construction sector of civil engineering all over the world. Bituminous mixtures are consisted of aggregates (coarse and fine aggregates), bitumen and fillers. Of these components aggregates play an important role.

2.1 Aggregates

Aggregate is defined as a granular material of mineral composition such as sand, gravel, shell, slag, or crushed stone used with a cementing medium to form mortars or concrete or alone as in base courses, railroad ballast [1]. Aggregates can be coarse or fine aggregates.

a) **Coarse aggregates:** Aggregate predominantly retained on the 4.75 mm (No.4) Sieve or that portion of an aggregate retained on the 4.75 mm (No.4) sieve [6].

b) **Fine aggregate:** sand, an unconsolidated (loose), rounded to angular rock fragment or mineral grain having a diameter in the range of 0.0635 to 2 mm (0.0025 to 0.08 in.),rounded fragments having a diameter of 0.074 mm (retained on U.S. standard sieve no.200) to 4.76 mm (passing U.S. standard sieve no. 4).

2.2 **Limestone aggregates**

Limestone is a sedimentary rock. Limestone is made up of varying proportions of following chemicals with calcium and magnesium carbonate being the two major components, as shown in Table2. The two main impurities are silica and alumina with iron as the third.

Table 1: Composition of limestone

Chemical composition	**Percentage (%)**
Calcium Carbonate	98
Magnesium Carbonate	1.08
Silica	0.32
Alumina	0.08
Iron (III) Oxide	0.06

For a general purpose lime, a limestone with SiO_2 content of up to 3.5% and Al_2O_3 content of up to 2.5% may be used where purer stone is not available, whereas lime for building or road construction purposes may have SiO_2 content of up to 10% (perhaps slightly more) and an Al_2O_3 content of 5 %. An Al_2O_3 proportion of greater than 5% will produce a semi-hydraulic or hydraulic lime [7].

2.2.1 Physical Properties of Limestone

The colour of most limestone is varying shades of grey and tan. The greyness is caused by the presence of carbonaceous impurities-and the tan by the presence of iron. It has been found that all limestone are crystalline but with varying crystal sizes, unit format, and crystal arrangement For lime production purposes there are two factors related to limestone crystallinity and crystal structure which are of specific interest.

Density or porosity is determined as the percentage of pore space in the stone's total volume. It ranges from 0.3% - 12%. At the lower end are the dense types (marble), and at the upper the more porous (chalk). Generally, the finer the crystallize, the higher the porosity but there are anomalies which suggest that each case be considered separately. A high porosity makes for a relatively faster rate of calcinations and more reactive quicklime.

Limestone varies in hardness from between 2 and 4 on Mohr's scale with dolomitic lime being slightly harder than the high calcium varieties. Limestone is in highest compressive strength whilst chalk has the lowest.

Due to the variance in porosity, the bulk densities of various limestone range from 2000 kg/m^3 for the more porous to 2800 kg/m^3 for the densest. The specific gravities of limestone range from 2.65-2.75 for high calcium limestone and 2.75-2.9 for dolomitic limestone. Chalk has a specific gravity of between 1.4 and 2. [3]

2.3 Granite

Granite is an igneous rock. The minerals that are found in granite are primarily quartz, plagioclase feldspars, potassium or K-feldspars, hornblende and micas. Quartz is usually the last mineral to crystallize and fills in the extra space of the other minerals. Quartz's hardness, lack of chemical reactivity and near lack of cleavage give granite significant amount of its desirable durable properties. The quartz will appear grey, but is actually colourless and is reflecting and fusing the colours of the white and black minerals surrounding it. Granite as it is the case in limestone aggregates, its properties are highly affected by its chemical composition. In the following table 2 the composition of granite is presented.

Table 2: Composition of granite

Chemical composition	**Percentage (%)**
Silica	70-77
Alumna	11-13
Potassium oxide	3-5
Soda	3-5
Iron	2-3
Lime	1
Magnesia and Titania	<1

<u>2.3.1 Physical Properties of Granite</u>

Granite is an acid crystalline igneous rock with a relative density of 2.65 - 2.75. A cubic meter of granite weighs on the order of 2.66 tons or almost two tons cubic yard. Its physical hardness varies principally according to composition, and with the proportion and type of feldspar present.

Because granites develop by slow and complete crystallization of the molten magma, porosity and permeability are typically low. Porosity is consistently low in granite, with values on the order of 0.1 to 1.2 percent being characteristic. Being crystalline, granite has low permeability when fresh, though weathered rocks are much more permeable. In outcrops and near-surface zone, however, it is commonly fissured and fractured and is therefore pervious.

2.3.2 Mechanical Properties of Granite

Like many igneous rocks it exhibits a high compressive strength usually more than 200 MPa [3]. It has a significantly high average strength which can be explained by its petrography. It is explained that, crystal size is the primary strength factor in granite [8]. The corresponding reduction in crystal interlock and the influence of crystal cleavage with increased crystal size result in a wide strength range as one progresses from fine grained granite to coarse grained granite.

Reduction in compressive strength is the most obvious and important geotechnical factor caused by chemical weathering or alteration of intact rock. The following are the range of compressive strength for different weathered states of granite [9]:

- ✓ Fresh> 250 MPa
- ✓ Discoloured 100-250 MPa
- ✓ Weakened 25-100 MPa
- ✓ Soil **<** 2.5 MPa.

This is a corresponding reduction in the modulus of elasticity with increasing degree of weathering. The changes in strength and elasticity resulting from chemical weathering or alteration are dependent on the susceptibility of rock composition to weathering when all other factors such as time and climate being equal.

2.4 Limestone and Granite in Perak

The geology of Perak is like the rest of the country i.e. granite, limestone, slates and traces of basaltic rock. As one goes from east to west, it is more likely to see clays and partly decomposed slates, sandstones and laterite in Perak [10]. There are also rounded fragments of quartz of various colours generally opaque white, but also red, brown rose colour and violet. Figure 1 below shows the distribution of aggregates and minerals in Perak.

2.4.1 Granite in Perak

A range of granite rocks are found in Thaiping. Alluvial of the valley of the Perak River is consisted of the spurs of the Granite Mountains [11]. Another granite source is found in the Kinta range which divides the Perak River and the River Kinta. The whole of the Thaiping Range and the rock underlying the stream tin is a coarse bluish or grey granite [10]. It contains little mica, large contents of feldspar, with cassiterites, iron, manganese and quartzes paste. There is another granite mountain chain which is found in the Kinta region [11]. In this region the granite it is rarely observed that some limestone layers in embedded in the granite. Going from north to south it is customary to find a chain of granite range but in diverging fashion in which the range will eventually disappear in the south of Perak [10].

2.4.2 Limestone in Perak

There are isolated formations of the limestone in the Valley of Perak River. Limestone is also observed in the alluvial of Kinta Valley [11]. A large deposit of limestone also can be found by the side of Kampar River [10]. There is a limestone range as one goes from centre of Perak to westward. But it is almost in cone shaped pattern as the range is discontinuous for a small gap.

Figure 1: Limestone and granite distribution of Perak

2.5 Kampar quarry

Kampar quarry is located in Kampar Perak and the area is believed to cover about 194 acres of land with 260 million tons of limestone [12]. Some part of it is currently run by Unichamp Mineral Sdn. Bhd. under Subcontractor Fineplus (M) Sdn. Bhd. The limestone from this quarries is used as aggregates as well as other a range of purposes. It can be used as quick lime, lime milk, powder and slaked lime.

Figure 2: Map of Kampar quarry

Figure 3: Photo of Kampar quarry site

2.6 Kampung Keramat Pulai Quarry

Kampung Keramat Pulai quarry is located at 31300 Kampung Kepayang, Perak. This quarry has both limestone and granite aggregates. The granite quarry is being developed by a company called Lafarge. It covers a size of 39.99 hectares. [13]

Figure 4: Map of kampong Keramat Pulai

Figure 5: Photo of Keramat Pulai quarry

2.7 Mukim Sungai Raya Quarry

Mukim Sungai raya is located at 31300 Simapang Pulai District of Kinta, Perak. This quarry is found in the Kinta Valley - the largest limestone reserve in Malaysia [14]. The quarries is run by seven different companies but for this project, an aggregate quarry operated by Anting Sdn Bhd is considered.

Figure 6: Map of Mukim Sungai raya

Figure 7: Photo of Mukim Sungai raya

2.8 Lahat Quarry

Lahat is located at Pusing 31550, Perak. Operated by a lot of companies, the quarry owned by Manjung Granite Sdn. Bhd. was the one used for this project.

Figure 8: Map of Lahat Quarry


Figure 9: Photo of Lahat quarry

CHAPTER 3. METHODOLOGY

The potentials of the granite and limestone as construction aggregates for highway construction are assessed through several processes. Specimens for all tests will be prepared from the collected aggregate samples from the four quarries according to the specifications for respective tests. For the preliminary stage of the study, lab test will be done on each of the design material; bitumen, filler and also the aggregates.

All the data from the experiment will be collected and will be used in the next stage of the study, which is to conduct Marshall Test on the mix design. The mix will be using the same materials tested in the preliminary stage.

3.1 Determination of Aggregate Properties

3.1.1 Physical Properties

Specific Gravity and Water Absorption Test

Specific gravity of an aggregate is considered as a measure of quality or strength of material. Aggregate generally contains pores, both permeable and impermeable. Aggregates having low specific gravity values are generally weaker than those having higher values. Aggregate with higher water absorption value are porous and thus weak. The test was carried out according to the ASTM Designation: C 127-88.

The aggregate sample was first dried and immersed in water for 24 hours. Then, it was removed from the water and surface dried. The mass of the saturated surface dried sample was determined. The saturated surface dried sample was immediately placed in container and its weight in water was determined. Finally, the sample was dried in oven and weighed a third time. The following formulas are used to determine the specific gravity of aggregates.

Particle density on an oven-dried basis = $\frac{D}{A-(B-C)}$ (3.1)

Particle density on a saturated and surface-dried basis = $\frac{A}{A-(B-C)}$ (3.2)

Apparent particle gravity = $\frac{D}{D-(B-C)}$ (3.3)

Where: A= Mass of saturated surface-dry sample in air (g).

B= Mass of vessel containing sample and filled with water (g).

C= Mass of vessel filled with water only (g).

D= Mass of oven-dry sample in air (g).

The water absorption was expressed as the percent water absorbed in terms of oven dried weight of aggregates. Thus,

Water Absorption (% of dry mass) = $\frac{1 \quad (A-D)}{D}$ (3.4)

3.1.2 Mechanical Properties

Los Angeles Abrasion Test

It is important to find the amount of wear of aggregate used in road construction work as the aggregate will be subjected to heavy traffic loads. For this purpose, Los Angeles test will be carried out according to ASTM Designation: C 131-89. This test was performed to determine the abrasive resistance of aggregate by abrasion, attrition and impact. The principle of this test is to find the percentage wear due to relative rubbing action between the aggregate and steel balls used as abrasive charge. Pounding action of these balls also exists during the test and hence the resistance to wear and impact will be evaluated by the test. Attrition is caused by the frictional resistance between the aggregate particles.

The test utilizes the Los Angeles machine consisting of a rotating hollow cylinder with abrasive charge of steel spheres averaging 46.8 mm in diameter each weighing between 390 and 445 g, and rotated at 30-33 rpm for 500 revolutions. The result of the test is expressed as the percentage by mass of material passing a No. 12 ASTM sieve (equivalent to a No. 10 BS sieve) after test. ASTM states that there are two different version of Los Angeles Abrasion test: one is for the coarse aggregate (ASTM C131) and the other for the fine aggregates (ASTM C535). The suggested maximum Los Angeles values for bituminous materials is found to be 40 whereas for concrete is 50. Typically, coarse aggregates have a Los Angeles abrasion value of 20% or lower; on the other hand soft aggregates like limestone have a typical abrasion value of 50% or higher. Abrasion values of greater than 50% is not recommended for road works.

The following formula is used to determine the Los Angeles abrasion value of an aggregate.

$$\text{Los Angeles abrasion value} = \frac{M_2}{M_1} \times 100\% \qquad (3.5)$$

Where: M_1 is mass of aggregate retained on No.4 ASTM sieve (4.75 mm)

M_2 is mass of aggregate passing through No.12 ASTM sieve (1.70 mm)

Aggregate Impact Value Test

This test is performed to evaluate the toughness or resistance of aggregate to fracture under repeated impacts. The aggregate impact value indicates a relative measure of resistance of aggregates to impact with different effect than the resistance to gradually increasing compressive stress. The method of *Determination of Aggregate Impact Value* BS: 812 Part 3 was used for this test. Impact test machine comprises a metal base and a cylindrical steel cup with internal diameter 10.2 cm and depth *5* cm where the aggregate specimen is placed; a metal hammer of 13.5-14.5 kg having a free fall from height 38 cm was arranged to drop through vertical guides.

Dry aggregate sample passing 12.5 mm sieve and retained on 10 mm sieve is filled in cylindrical measure in three layers by tamping each layer by 25 blows. It is transferred from the measure to the cup of the aggregate impact testing machine and compacted by single tamping of 25 strokes. The hammer is raised to a height of 38 cm above the upper surface of the aggregate in the cup and then allowed to fall freely on the specimen. After subjecting the test specimen to 15 blows, the crushed aggregate is sieved on 2.36 mm (no.8) sieve. The aggregate impact value is then expressed as the percentage of the fine formed in terms of the total weight of the sample taken.

The aggregate impact value is calculated using the following formula

$$AIV = \left[\frac{(W_1 - W_2)}{W_1}\right] \times 100\% \quad (3.6)$$

Where: W_1 is the weight of original sample

W_2 is the weight of aggregate passing through Sieve No.8 (2.36 mm)

3.2 Determination of Bitumen Properties

Standard Penetration Test for Bitumen

The test is used to determine the grade of bitumen. The penetration tests determine consistency of bitumen for the purpose of grading. Depth in units 1/10 of millimetre to which a standard needle having a standard weight will penetrate vertically in a duration of five seconds at a temperature of 25°C determines penetration for gradation. Hence the softer the bitumen, the greater will be its number of penetration units.

Ring and Ball Test (Softening Point)

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

3.3 Determination of the Filler Properties

The specific gravity of filler is determined by using Ultrapycnometer 1000, Figure 10. The weight of filler to be tested is taken. Specific gravity of filler will be observed as the apparatus gives the reading once the filler was fed in to the cell.

Figure 10: Ultrapycnometer 1000

3.4 Marshall Mix Design

Marshall Mix design is one of the oldest design methods used. The Marshall method criteria allows the engineer to choose an optimum asphalt content to be added to specific aggregate blend to a mix where the desired properties of density, stability and flow are met. The Marshall method uses standard HMA samples that are 100 mm (4-inch) diameter cylinder and 64 mm (2.5 inches) in height (corrections can be made for different sample heights).

The preparation procedure is carefully specified, and involves heating, mixing, and compacting asphalt/aggregate mixtures. Once prepared, the samples are subjected to a density-voids analysis and to a stability-flow test. The aggregate, granite is placed in the oven to dry to a constant temperature at 150° C. The asphalt binder used is Penetration Grade of 80-100. Three specimens are prepared at each of the five percentages of the asphalt at 4.5%, 5.0%, 5.5%, 6.0% and 6.5% (Percentage of weight of the total mixture).

The heated aggregates and the asphalt cement are mixed thoroughly in the mixer. The HMA in the mould is compacted using the Gyratory Testing Machine. Both faces of the specimen are compacted with 75 blows to simulate a heavy traffic greater than 1 million Equivalent Single Axle Load (ESAL). Samples are extruded from olds and left to cool down before starting the bulk specific gravity (Gmb) test: ASTM 02726 Bulk Specific Gravity of Compacted Bituminous Mixtures. The weight of each specimen in air and water and its height should be taken (for density calculations). The whole procedure will be repeated using limestone aggregate

3.4.1 Determination of Marshall Mix Design

The stability and flow tests are run using the semi-circular test head in conjunction with the Marshall testing machine. The specimen is immersed in a bath of water at a temperature of 60°C for a period of 30 minutes. It is then placed in the Marshall Testing Machine, as shown in Figure 4, and loaded at a constant rate of deformation on 5mm per minute until failure occurs. The stability of the sample is determined at the peak load crushing the sample in the loading head in Newton. The flow is also measured as the highest deflection at the peak load.

The optimum asphalt binder content is finally selected based on the combined results of Marshall Stability and flow, density analysis and void analysis. Plots of asphalt binder content versus measured values of unit weight, flow, Marshall Stability, porosity, and %VMA are generated. Optimum asphalt content is also selected corresponding to air voids of 4%. The values of the other properties at this percentage of asphalt are determined and compared to specifications. The optimum bitumen content will be compared to determine the best aggregate and gradation for bituminous mixtures.

3.5 Preparation of Materials

The aggregates which are collected form the four different quarries are well graded for both the limestone and granite batches. In table 12 below, the combined gradation of fine aggregates, coarse aggregates and ordinary Portland cement (OPC) which is added as adhesive and anti-stripping agent is shown. Prior to any test conducted on the aggregates, all the aggregates are washed in order to remove the dust particle.

Table 3: Composition of Coarse aggregate, Fine aggregate and Ordinary Portland Cement for well graded aggregate

Material	Gradation (%)
Coarse aggregate	42
Fine aggregate	50

Filler (Ordinary Portland Cement)	8

Sieving analysis, as suggested by JKR manual on pavement deign, is conducted on each samples of the aggregates. The aggregates on each sieve must add up to give a total mass of 1.2kg. The gradation of the 1.2kg aggregate which in accordance to the JKR requirement is shown below in table 4.

Table 4: Well gradation limit for asphaltic concrete

Mix Type	**Wearing Course**
Mix Designation	**AC14**
B.S Sieve Size (mm)	**% Passing by weight**
37.5	-
28.0	-
20.0	100
14.0	80-95
10.0	68-90
5.0	52-72
3.35	45-62
1.18	30-45
0.425	17-30
0.150	7-16
0.075	4-10

Source: Manual on Pavement Des1gn, Jabatan Ke!Ja Raya (JKR).

The summary of the methodology is presented in the figure 11 below.

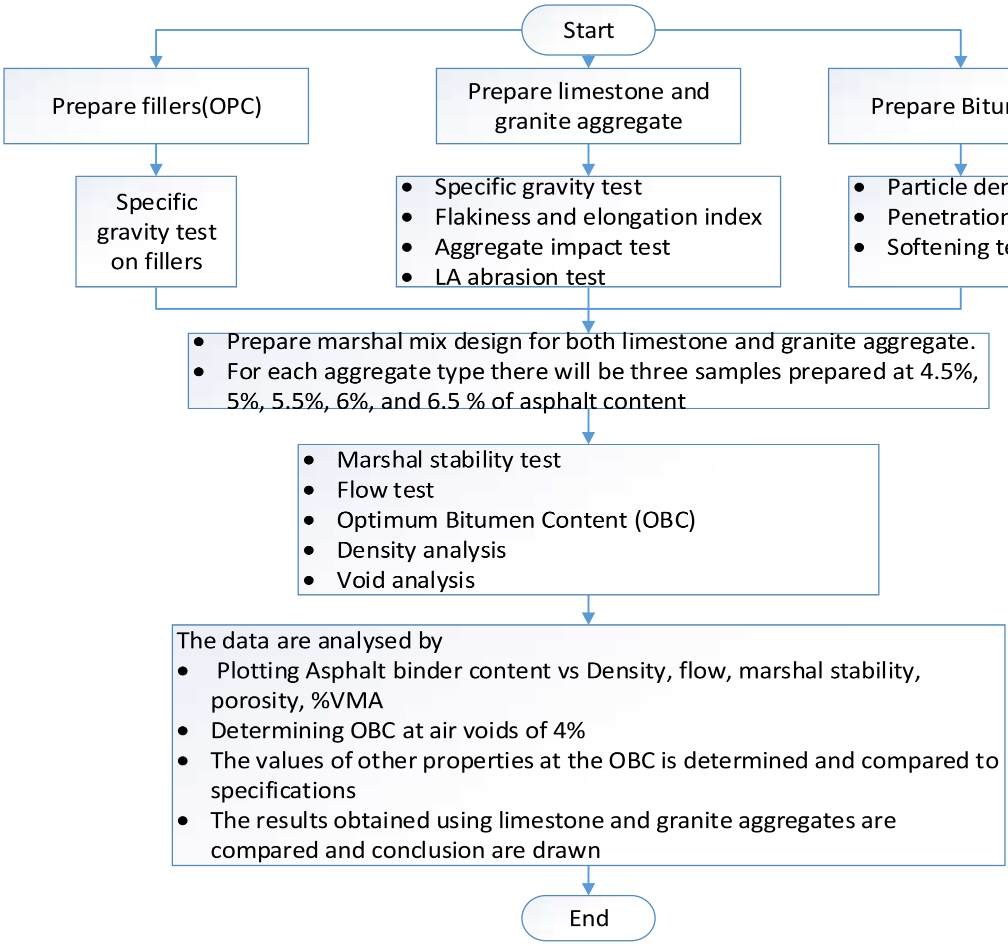

Figure 11: Summary of Methodology

3.6 Health, Safety and Environment (HSE) Analysis

Labs with the heavy machines, chemicals and other equipment present a health risk. Following the procedures precisely and careful utilization the material are needed for both safe working environment and better experimental results. A better way to achieve great result in health, safety and environment is to fully understand the potential risks and hazards that come when handling lab materials and then to use a proper safety measures to avoid the risks.

Potential sources of hazards in the highway lab are physical damages when transporting materials like aggregates, exposure to heat, noise and dust. Manual transportation of heavy aggregates or other lab materials may result musculoskeletal injuries if excessive force is used; and the materials being transported may fall down on the person handling it. Noise in the highway lab may come from lab equipment such as Los Angeles abrasion test machine. Noise can cause a temporary change of hearing or a short lasting ringing voice in ears. The sources of heat in the highway lab can be the oven or heating of materials like bitumen. Dusts may come from sieving analysis, during compaction or crushing of aggregates.

Bitumen in use, for example, on roads, roofs or pavements, are inert and do not present any known health or environmental hazard [16]. However, bitumen becomes hazards when heated emitting hydrocarbons to which the workers may be exposed. These fumes, after long exposures, can cause eye, throat and nasal irritation [11].

Therefore appropriate measures should be taken to avert the above health risks. Transporting of heavy lab materials should be done using trolleys, wheelbarrows or other transporting equipment. Safety shoes must be worn all the time. Exposure to heat can be avoided by using hand gloves when handling hot materials and dust masks should be used to avoid respiratory health risks. Noise cancelling headset are advised to minimize health risks arising from noise.

CHAPTER 4: RESULT

Physical and mechanical properties of aggregates, the properties of bitumen and the properties of filler were determined by conducting the appropriate laboratory tests. These particular tests are done so that the above mentioned materials confirm to the requirements set by JKR. Therefore, in this result section of the report, I will discuss the results of the laboratory tests that I conducted.

4.1 Physical Properties of Aggregates

Two tests were done to investigate the physical properties of the aggregates from each of the four quarries. They were Particle Density (Specific Gravity), and Water Absorption.

4.1.1 Aggregate Particle Density (Specific Gravity) & Water Absorption

Specific gravity is found by dividing the unit weight of aggregate by the unit weight of water. It is used in calculating air voids, voids in mineral (VMA), and voids filled by asphalt (VFA). Water absorption can be an indicator of asphalt absorption and may also give indications of the frost susceptibility or other weakness of an aggregate. A highly absorptive aggregate could lead to a low durability asphalt mix. The aggregates from the quarries were used as a source of coarse aggregates and their water absorption capacity and particle density were determined and presented below. Sand was used as a fine aggregate and its properties was determined prior to mixing with bitumen so that it can confirm to JKR standard.

Table 5: Particle Density and Water Absorption value for different quarries and sand

Properties	**Lahat quarry**	**Kampung Keramat Pulai quarry**	**Kampar quarry**	**Mukim Sungai Raya quarry**	**Fine aggregates (Sand)**
Water absorption (%)	1.15	1.05	2.79	3.07	0.51
Specific gravity	2.55	2.6	2.50	2.52	2.57

In table 5 above, Lahat and Kampung Keramat Pulai quarries, which are consisted of granite aggregates, have 1.15 % and 1.05 % respectively. The JKR manual specifies that the water absorption value of an aggregate should be less than 2% in order to be used in road works. Therefore, these two quarries have met the requirement in terms of water absorption capacity. The fine aggregates which is sand was found to have a water absorption value of 0.51 which also meets JKR standards. However, Kampar and Mukim Sungai Raya quarries have a water absorption values of 2.79 % and 3.07 % respectively which is greater than the maximum 2% in the JKR specification. Kampar and Mukim Sungai Raya quarries supply limestone aggregates which explains why they have higher water absorptions. This is because limestone has higher porosity compare to granite. The low porosity of granite is caused by slow and complete crystallization of the molten magma during development.

In the table 7, the specific gravity of the aggregates from different quarries were presented. Lahat and Kampung Keramat Pulai quarries have specific gravity of 2.55

and 2.66 respectively, higher specific gravities than Kampar and Mukim Sungai Raya quarries which are 2.50 and 2.52 respectively. Granite has higher specific gravity compared to limestone because the structure of granite is well packed compared to porous limestone.

4.2 Mechanical Properties of Aggregates

Two tests were conducted in order to determine the mechanical properties of the aggregates; they were aggregate impact value test and Los Angeles abrasion value test. The aggregate impact value test was carried out to determine the toughness of the aggregates when they are exposed to traffic loads.

4.2.1 Aggregate Impact Value test

Two tests were conducted for aggregates from ach quarries. The results are shown in Table 6, 7, 8 and 9.

Table 6: Result for Aggregate Impact Value Test for Lahat quarry

		Test No.	
		1	2
Net weight of the aggregate in the (A)	(g)	801	796
Weight of aggregates coarser than 2.36 mm. (B)	(g)	624	620.6
Weight of Sample retained in the pan (C)	(g)	177	175.4
Aggregate impact value	(%)	22.1	22.04

Table 7: Result for Aggregate Impact Value Test for granite Kampung Keramat Pulai quarry.

		Test No.

		1	2
Net weight of the aggregate in the (A)	(g)	805	803.1
Weight of aggregates coarser than 2.36 mm. (B)	(g)	618.02	617
Weight of Sample retained in the pan (C)	(g)	186.98	186.1
Aggregate impact value	(%)	23.23	23.17

Table 8: Result for Aggregate Impact Value Test for granite Kampar quarry.

		Test No.	
		1	2
Net weight of the aggregate in the (A)	(g)	904.8	892
Weight of aggregates coarser than 2.36 mm. (B)	(g)	675.09	668
Weight of Sample retained in the pan (C)	(g)	229.71	224
Aggregate impact value	(%)	25.38	25.11

Table 9: Result for Aggregate Impact Value Test for granite Mukim Sungai Raya quarry.

		Test No.	
		1	2
Net weight of the aggregate in the (A)	(g)	913.6	916.25
Weight of **aggregates** coarser than 2.36 mm. (B)	(g)	684	672.3
Weight of Sample retained in the pan (C)	(g)	229.6	243.95
Aggregate impact value	(%)	25.13	26.62

4.2.2 Los Angeles Abrasion test

Los Angeles abrasion test measures the degradation of aggregates by a specified number of steel balls and rotating drum. The aggregate was subjected to the abrasion effect of the steel spheres, the friction force between the aggregates and the impact effect of the rotating drum which have crushing effect. The aggregates from Mukim Sungai Raya and Kampar quarries were expected to have a higher abrasion value as they are consisted of limestone aggregates.

The results for each of the four quarries are given below in Table 10, 11, 12 and 13. Kampung Keramat Pulai and Lahat have higher abrasion values of 18.34 % and 26.54 % respectively. Mukim Sungai Raya quarry has an abrasion value of 53 % while Kampar has 48 %.

Table 10. Result for Los Angeles Abrasion value test of Kampung Keramat Pulai quarry

		Test 1
Mass of aggregate retained on No. 4 ASTM sieve (4.75 mm), M_1	kg	5.0
Mass of aggregates Passing No.12 ASTM sieve (1.70 mm), M_2	kg	0.917
Los Angeles abrasion value $\frac{M_2}{M_1}$ x 100 %	%	18.34

Table 11: Result for Los Angeles Abrasion value test of Lahat quarry

		Test 1
Mass of aggregate retained on No. 4 ASTM sieve (4.75 mm), M_1	kg	5.0
Mass of aggregates Passing No.12 ASTM sieve (1.70 mm), M_2	kg	1.15
Los Angeles abrasion value $\frac{M_2}{M_1}$ x 100 %	%	26.54

Table 12: Result for Los Angeles Abrasion value test of Mukim Sungai Raya quarry

	Test 1

Mass of aggregate retained on No. 4 ASTM sieve (4.75 mm), M_1	kg	5.0
Mass of aggregates Passing No.12 ASTM sieve (1.70 mm), M_2	kg	2.65
Los Angeles abrasion value $\frac{M_2}{M_1}$ x 100 %	%	53

Table 13: Result for Los Angeles Abrasion value test of Kampar quarry

		Test 1
Mass of aggregate retained on No. 4 ASTM sieve (4.75 mm), M_1	kg	5.0
Mass of aggregates Passing No.12 ASTM sieve (1.70 mm), M_2	kg	2.4
Los Angeles abrasion value $\frac{M_2}{M_1}$ x 100 %	%	48

From the results, it is shown that the quarries which are consisted of limestone aggregates have relatively higher Los Angeles abrasion value. Aggregates with higher abrasion values are not desirable as they provide less resistance against skidding. The JKR stated that the Los Angeles abrasion value of an aggregate must not be greater than 60 % in order to be used in road construction. Since all the quarries recorded an abrasion value less than 60 % it can be concluded that they meet the requirement. However, the abrasion test is empirical and there it doesn't show direct relationship with the field performance of the aggregate [17]. The overall comparison of the properties of aggregates from the quarries with the JKR requirements is tabulated below.

Table 14: Comparison between Aggregate Properties and JKR Requirements

Properties	**Lahat**	**Kampung Keramat Pulai**	**Mukim Sungai Raya**	**Kampar**	**JKR requirement**
Water absorption (%)	1.15	1.05	3.07	2.79	Less than 2
Specific gravity	2.55	2.6	2.52	2.50	-
Aggregate impact value (%)	22.07	23.2	25.88	25.25	Between 9-33 for granite and 17-35 for limestone

Los Angeles abrasion value (%)	26.54	18.34	53	48	Not more than 60%

4.3 Properties of Bitumen

The bitumen Penetration Grade used in the tests is 80-100. In order to investigate the properties for this type of bitumen, three tests are allocated. The tests are Standard Penetration Test, Ring and Ball Test (Softening Point), and Particle Density Test (Specific Gravity).

4.3.1 Standard Penetration Test

Penetration test measures the consistency of a penetration or oxidized bitumen. In order to obtain the penetration value of the bitumen, 2 sample were tested. Determinations of penetration value were done three times to get the mean value. The results of the test are presented in the following Table 15.

Table 15: Result for Standard Penetration Test

STANDARD PENETRATION TEST -BS2000: Part 49: 1983/ ASTM DS				
Temperature: 25°C		Load: 100 g	Time: 5 sec	
Sample No.	Determination 1	Determination 2	Determination 3	Mean
A	85	88	87	87
B	88	88	86	87

As to report the standard penetration value of the bitumen sample, the mean value of the two samples, A and B is taken, which is 87. According to bitumen properties by JKR, standard penetration value must be between 80 and 100 (for penetration grade 80-1 00). Thus the bitumen that will be used for the later part of the study fulfils the requirement by JKR in terms of standard penetration.

4.3.2 Specific Gravity Test

Pycnometer was used to determine the specific gravity of bitumen. A total of 2 samples were tested and the results are presented in Table 16. The average specific gravity value was found to be 1.025. This value complies with the standard specific gravity value for bitumen, which is between 1.02 and 1.04.

Table 16: Result for specific gravity test of bitumen

			Test No.	
			1	2
Mass of pycnometer and stopper,	A	(g)	19.1	19.3
Mass of pycnometer filled with water,	B	(g)	45.4	45.6
Mass of pycnometer filled with bitumen,	C	(g)	31.2	31.3
Mass of pycnometer filled with asphalt and water	D	(g)	45.7	45.9
Relative Density			1.025	1.026

In the above table the relative density is found using the following formula

$$\text{Relative density} = \frac{(C-A)}{[(B-A)-(D-C)]} \quad (4.1)$$

4.3.3 Softening Point Test

Softening point test was conducted to determine the softening point of bituminous binder. A total of 2 samples were tested. The results of the test are shown in Table 17 below.

Table 17: Result for Softening Point Tests.

SOFTENING POINT TEST BS2000: Part 58; 1983/ ASTM D36*			
Sample No.	Ball 1	Ball 2	Mean
A	51.6	52	51.8
B	49	49.3	49.15

The result obtained shows two mean values of 51.8°C and 49.15°C which when averaged gives us 50.5°C. Based on the Manual on Pavement Design, the requirement for softening point of 80-100 bitumen is not less than 45°C and not more than 52°C. For both sample A and B, the softening value comply with the standard, therefore it can be take into consideration.

The slight difference between the two mean values might occur due to human error and also experimental error. The procedure for carrying out the softening point must be followed precisely to obtain accurate result. Sample preparation, rate of heating and accuracy of temperature measurement are critical. Automatic softening point machines can be used as it can ensure close temperature control and which automatically record the result at the end of the test. As a result, errors can be eliminated and more accurate result can be obtained.

Table 18 shows the summary of comparison between bitumen properties and JKR requirements. As discussed before, all the properties lie within the allowable limit and thus can be used in the later part of the project.

Table 18: Comparison between Bitumen Properties and JKR Requirements

Properties	**Bitumen Grade 80-100**	**JKR Requirements**
Standard Penetration (1/100 cm)	87	Between 80 and 100
Specific Gravity	1.025	Between 1.02 and 1.04
Softening Point (°C)	50.5	Not less than 45 & not more than 52

4.4 Properties of Filler

The type of filler that will be used in the bituminous mixture is Ordinary Portland Cement (OPC). The test was conducted by using Ultrapycnometer 1000. The result can be obtained simultaneously after the test.

Weight= 3.78 gram

Table 19: Specific Gravity Test for OPC.

Run	Volume (cm^3)	Density (g/cm^3)
1	1.13	3.34
2	1.14	3.32
3	1.14	3.32
4	1.14	3.32
5	1.13	3.34
6	1.14	3.32
Average	1.14	3.32

This test was done in order to get the specific gravity value for OPC. From the result obtained shown in Table 19, the average specific gravity value of OPC is 3.32.

4.5 Properties of Bituminous Mixture

Initially, 60 samples were prepared from all the four quarries with each of the quarries contributing 15 samples. The bulk specific gravity, the percentage of voids in the mineral aggregate (VMA) and the porosity of the samples is determined. Then, the samples were tested in Marshal testing machine to determine the optimum bitumen content, Marshal stability and flow.

First, the average bulk specific gravity of the samples were determined. Then, the average bulk specific gravity is multiplied by the density of water (γ_w) to obtain the average unit weight of each sample. Properties such as VMA (percent of voids in mineral aggregates) and porosity were calculated.

For all quarries, the average of the results of the density of the samples at each bitumen content was calculated. The same was done for Marshal Stability, flow and Porosity. Then, the optimum bitumen content was determined by talking the average of the bitumen content at which the porosity (percent of air void) is at 4 %, the Marshall Stability is the highest and the bulk density is maximum.

4.5.1 Analysis of Marshal Test Results

The graphs of density, VMA, Marshal Stability and flow are plotted in the following figures 12, 13, 14, 15 and 16.

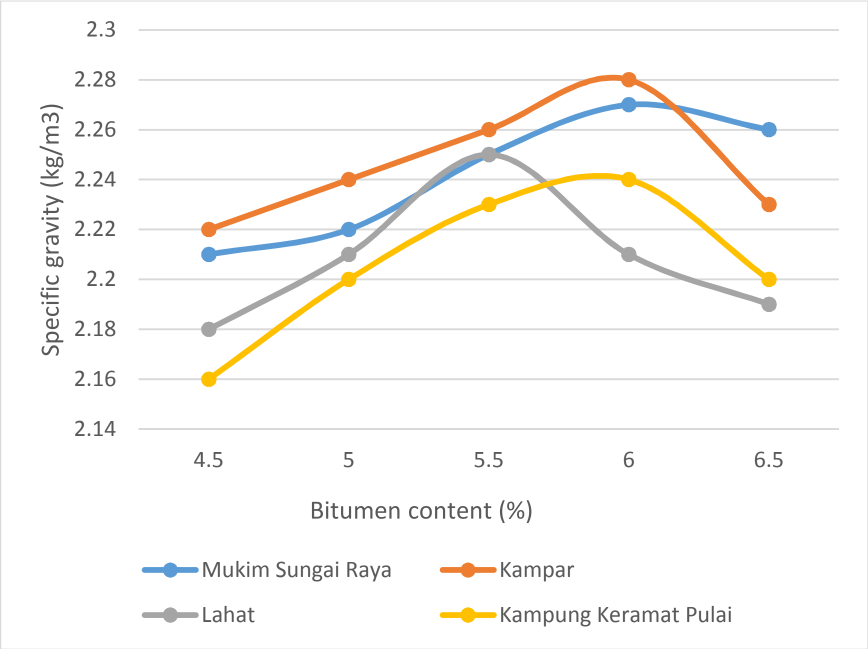

Figure 12: Specific gravity vs bitumen content

The values for unit weight (density) were obtained by measuring the mass of the sample in water and in air. Each value is determined by measuring the average density of the samples at each bitumen content. Figure 12 shows the density of the bituminous mixtures prepared from each of the quarries. Kampung Keramat Pulai and Lahat quarries were expected to have a higher density values as they are comprised of granite, however, Mukim Sungai Raya and Kampar quarries have higher results.

As the mixture samples were prepared, they were compacted using Gyratory Compaction Machine which results in crushing the aggregates. In the case of Mukim Sungai Raya and Kampar quarries which are limestone quarries, the aggregates tend to be crushed during the compaction process. Once the aggregates are crushed, they turn to be finer particles which fill up the voids and decreases the porosity. Therefore, during measurement of the mass in water, the mass of this sample is higher than the mass of other samples with higher porosity. This gives the quarries containing limestone aggregates (i.e. Mukim Sungai Raya and Kampar) higher density.

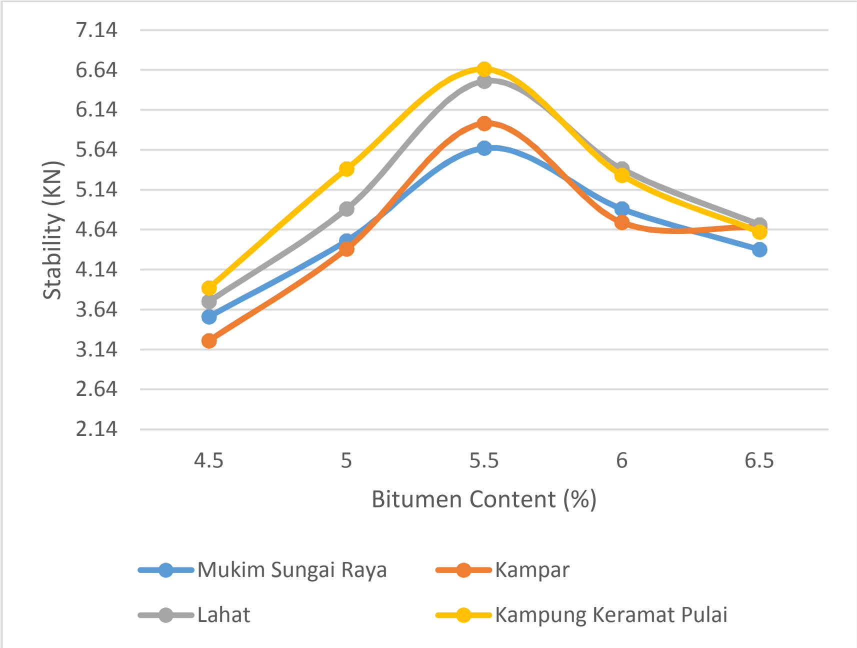

Figure 13: Stability vs bitumen content

The marshal stability of the bitumen mix prepared from the aggregates from each quarries at different bitumen content is shown in figure 13 above. Initially, the Marshal Stability values are directly obtained from the Marshal Testing Machine. However, the values obtained from the testing machine needs to be multiplied by certain correction factors which are based on the height of the mix sample. The marshal stability values show that the maximum load the sample can be subject to before it fails. In figure 6, it is shown that Kampung Keramat Pulai and Lahat quarries have higher Marshal Stability than Kampar and Mukim Sungai Raya quarries. This is because the aggregates from Kampung Keramat Pulai and Lahat are granite aggregates whereas limestone comprises the other two quarries.

For all the quarries, initially, the marshal stability increases then it reaches a maximum value and starts to decrease. This is because the strength of the bitumen mix comes from both the interlocking of well graded aggregates and the bond between the bitumen and the aggregates. As the bitumen content is increased, the bond between the aggregates and the bitumen increases resulting in higher Marshal Stability values. However, if the bitumen content exceeds a certain label the voids will be filled with the bitumen which results the load being transmitted by hydrostatic pressure through the bitumen in turn reducing the stability values.

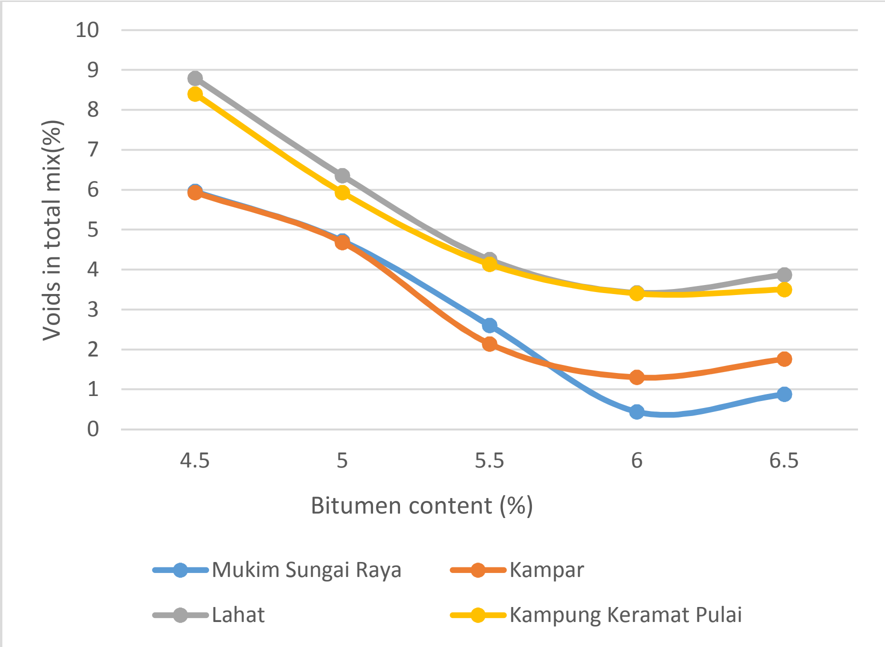

Figure 14: Voids in total mix vs bitumen content

In figure 14 above, the percentage of voids in the mix against the binder content is shown. From the graph, aggregates from Kampung Keramat Pulai and Lahat show a relatively higher percentage of voids than their counterparts from Mukim Sungai Raya and Kampar quarries. As the later are comprised of limestone aggregate, it undergoes degradation while being compacted in the gyratory machine; thus crushed into smaller sizes and filled some of the voids. However, the aggregates from Kampung Keramat Pulai and Lahat quarries can resist the crushing effect of the gyratory compaction machine due to their granite nature and will have a higher porosity.

Voids in the total mix is the parameter which indicates the porosity of the mixture. If the amount of air voids in the mixture reaches above the required quantity, it may introduce cracking in the mixture as there is no sufficient bitumen to coat all the aggregate surface. If too low air voids are present, there won't be enough room to contain the bitumen thus resulting in bleeding or plastic flow of bitumen which is termed as rutting. Therefore, the percentage of air void in the total mix is limited to 3-5 % and the mean 4% is taken in the calculation of the optimum bitumen content.

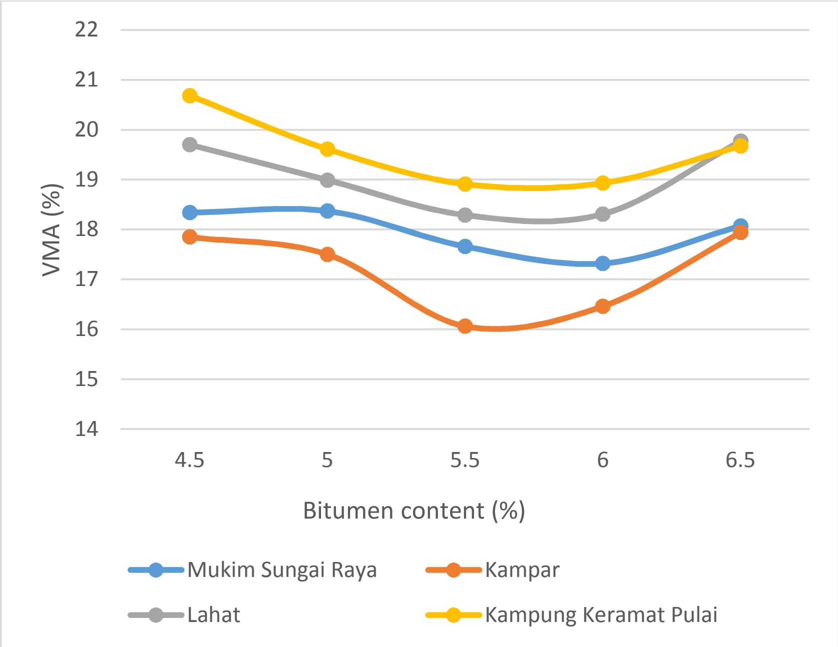

Figure 15: Graph of voids in mineral aggregates vs bitumen content

In figure 15, relatively Kampung Keramat Pulai and Lahat quarries show higher voids in their mineral aggregates. VMA is the volume of void when there is no bitumen in the void of the aggregates. Too low VMA is not recommended as there will not be enough room left to add the bitumen so that it can adequately coat the surface of the aggregates. Excessive VMA also disrupts the stability of the mixture [17]. Generally a minimum VMA of 17 % needed.

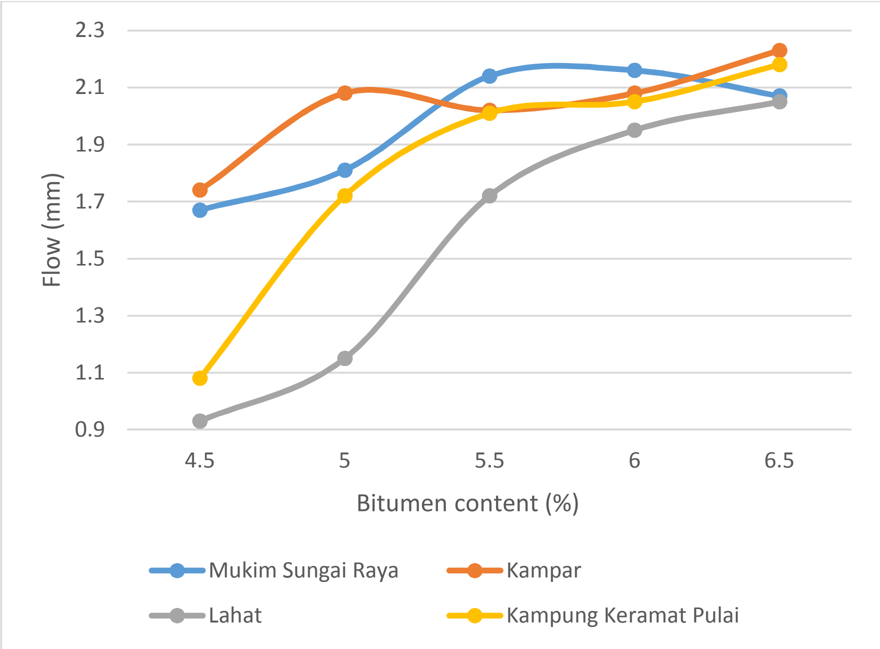

Figure 16: Flow vs Bitumen content

The flow value refers to the total amount of deformation that occurs up to the point where the load begins to decrease. Flow value has a significant correlation with the amount of bitumen used in the mixture. According to Figure 16, it is shown that as the bitumen content in the mixture increased, the value of flow increased. Relatively, the quarries made up of limestone (Mukim Sungai Raya and Kampar) seem to have higher flow values.

4.5.2 Determination of optimum bitumen content and comparison of bituminous mix properties with JKR requirements

The optimum bitumen content at which the mix can perform at its best in terms of voids in total mixture, density and Marshal Stability is first determined. Table 20 below shows the summary of the optimum bitumen content (OBC) for all of the four quarries.

Table 20: Optimum bitumen content for each quarry

Name of quarry	OBC (%)
Lahat	5.55
Kampung Keramat Pulai	5.68
Mukim Sungai Raya	5.72
Kampar	5.59

Using the above optimum bitumen content, the mixture samples were prepared. Then, Marshal Stability, flow and voids in total mix were determined and compared to the standards stipulated in JKR.

Table 21: Comparison between Properties of Design Mixes and JKR Requirements

Properties	JKR requirements	Lahat quarry	Mukim Sungai Raya quarry	Kampar quarry	Kampung Keramat Pulai.
Stability (kg)	More than 500	617	503	560	635
Flow (1/100cm)	20-40	17.4	20.8	20.3	21
Voids in total mix (%)	3-5	3.77	1.65	1.99	3.95

The JKR requirements specify that the stability for a sample should not less than 500kg. According to Table 21, values for stability for all the samples are exceeding 500kg.

It might be reasonable to believe that the best gradation is one that produces the maximum stability. This would involve a particle arrangement where smaller particles are packed between the larger particles, which reduce the void space between particles. This creates more particle-to-particle contact, which in HMA would increase stability and reduce water infiltration. From the table it is shown all the quarries containing limestone confirms to the JKR requirement, agreeing to the value of flow found earlier. On the other hand from the quarries containing granite only Kampung Keramat Pulai satisfied the JKR requirement. Therefore, we can deduce that Kampar, Mukim Sungai Raya and Kampung Keramat Pulai quarries can be used as a source of aggregate for road construction based on their flow values.

A value of 3-5 is the limit for voids in total mix according to JKR requirement. From table 21, only the quarries containing granite met the requirement. Granite itself is proven to have higher strength based on the AIV and LA test done in the earlier stage of the project. From all the quarries used for this project, only Kampung Keramat Pulai satisfied all the requirements set by JKR. Therefore, it is good enough to be used for road construction.

CHAPTER 5. CONCLUSION

The early stage for this project was more on investigating the properties of materials for bituminous mixture. The materials include aggregates, which are granite and limestone from four different quarries, bitumen, and filler (OPC). This purpose was achieved by conducting experiments in the lab and comparing the values of the properties obtained with the requirement from JKR. And the following conclusions are drawn.

i. From the result of particle density test, it is found that granite based aggregates from Lahat and Kampung Keramat Pulai quarries are denser than limestone based aggregates from Kampar and Mukim Sungai Raya quarries. This is because granite has a very well-packing structure due to its solidification process at the earlier stage of rock formation. The well-packing structure leads to a very low porosity of the rock.
ii. So from the water absorption value obtained, it can be concluded that limestone has higher porosity and weaker than granite. Thus, Kampar and Mukim Sungai Raya quarries contain more porous aggregates than Lahat and Kampung Keramat Pulai quarries.
iii. All the results for bitumen and filler are complying with the requirements and thus conforming that the materials are adequate to be used as a binder in bituminous mixtures.
iv. The aggregate were also undergone tests such us LA abrasion test and aggregate impact test. In which case, all of the quarries performed well to satisfy the JKR requirements.
v. In overall comparison only the aggregate from Kampung Keramat Pulai satisfied all the JKR requirements to be used in road construction. This is mainly due to the granite nature of the aggregates found in the quarry.

The test sample taken from each quarry are small compare to the sizes of the quarries. Therefore, it is important to recommend that additional samples be taken from the quarries and repeat the tests done in this project to confirm the results obtained here.

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APPENDICES

Appendix A

Marshal Test Results for all of the four quarries

MARSHALL MIX DESIGN & TEST: Kampar Quarry

Bitumen Grade: 80/100 Specific Gravity of Bitumen: 1.025 Specific Gravity of aggregate: 2.50

Coarse Agg: 42 %, 504 g Fine Agg: 50 %, 600 g Filler: 8 %, 96 g

Binder Content (%)	Sample No.	Height (mm)	Mass of specimen		Volume (cm^3)	Specific gravity		Air voids (%)		Flow (mm)	Stability (KN)		
			In air (g)	In water (g)		Bulk	Theory	Total mix	VMA		Measured	C.F.	Corrected
4.5	1	70.73	1239.5	677.5	562	2.22	2.36	5.93	17.85	1.75	3.71	0.86	3.19
	2	68.05	1197	663.5	533.5					1.73	3.45	0.96	3.31
5.0	1	69.71	1248	698	550	2.24	2.35	4.68	17.5	2.06	5.11	0.89	4.55
	2	70.98	1252	685	567					2.11	5.01	0.86	4.31
5.5	1	68.04	1221	641.5	579.5	2.26	2.31	2.14	16.06	2.01	7.22	0.83	5.99
	2	68.75	1236	684	552					2.02	6.70	0.89	5.96
6.0	1	69.83	1284	715.5	568.5	2.28	2.31	1.3	16.46	2.09	5.70	0.86	4.9
	2	69.10	1278.5	713	565.5					2.06	5.30	0.86	4.56
6.5	1	68.54	1258	712.5	545.5		2.27	1.76	17.94	2.25	4.96	0.93	4.61
	2	68.26	1290	710.5	579.5					2.21	5.67	0.83	4.71

MARSHALL MIX DESIGN & TEST: Mukim Sungai Raya Quarry

Bitumen Grade: 80/100 Specific Gravity of Bitumen: 1.025 Specific Gravity of Granite: 2.52
Coarse Agg: 42 %, 504 g Fine Agg: 50 %, 600 g Filler: 8 %, 96 g

Binder Content (%)	Sample No.	Height (mm)	Mass of specimen		Volume (cm^3)	Specific gravity		Air voids (%)		Flow (mm)	Stability (KN)		
			In air (g)	In water (g)		Bulk	Theory	Total mix	VMA		Measured	C.F.	Corrected
4.5	1	68.52	1219.5	697.5	522	2.21	2.35	5.96	18.34	1.71	3.65	1.00	3.65
	2	69.04	1196	673	523					1.63	3.60	0.96	3.46
5.0	1	69.01	1240	702	538	2.22	2.33	4.72	18.37	1.77	4.86	0.93	4.52
	2	69.25	1247	693	554					1.8	5.04	0.89	4.49
5.5	1	69.98	1273	704.5	568.5	2.25	2.31	2.6	17.66	2.15	6.78	0.86	5.83
	2	70.31	1268.5	716	552.5					2.13	6.17	0.89	5.49
6.0	1	70.18	1229.5	687.5	542	2.27	2.28	0.439	17.32	2.17	5.28	0.93	4.91
	2	68.52	1201	579.5	621.5					2.14	6.42	0.76	4.88
6.5	1	69.36	1284	715.5	568.5	2.26	2.28	0.877	18.07	2.07	5.08	0.86	4.37
	2	70.12	1278.5	713	565.5					2.08	5.14	0.86	4.42

MARSHALL MIX DESIGN & TEST: Lahat Quarry

Bitumen Grade: 80/100 Specific Gravity of Bitumen: 1.025 Specific Gravity of Granite: 2.55

Coarse Agg: 42 %, 504 g Fine Agg: 50 %, 600 g Filler: 8 %, 96 g

Binder Content (%)	Sample No.	Height (mm)	Mass of specimen		Volume (cm^3)	Specific gravity		Air voids (%)		Flow (mm)	Stability (KN)		
			In air (g)	In water (g)		Bulk	Theory	Total mix	VMA		Measured	C.F.	Corrected
4.5	1	70.37	1238	633.5	604.5	2.18	2.39	8.79	19.7	0.96	4.81	0.78	3.75
	2	71.02	1215.5	656.0	559.5					0.92	4.18	0.89	3.72
5.0	1	71.09	1267.9	695	572.9	2.21	2.36	6.35	18.99	1.23	5.72	0.86	4.92
	2	69.82	1250	684	566					1.11	5.67	0.86	4.88
5.5	1	71.51	1241.5	675	566.5	2.25	2.35	4.25	18.29	1.73	7.30	0.86	6.28
	2	70.53	1243	681	562					1.70	7.81	0.86	6.72
6.0	1	70.56	1269.1	678	591.1	2.21	2.29	3.42	18.31	1.96	6.94	0.81	5.62
	2	69.2	1250.5	686	564.5					1.93	6.24	0.86	5.37
6.5	1	70.38	1255	681	574	2.19	2.28	3.87	19.77	2.07	5.57	0.83	4.62
	2	68.91	1221	667	554					2.03	5.38	0.89	4.79

MARSHALL MIX DESIGN & TEST: Kampung Keramat Puai Quarry

Bitumen Grade: 80/100 Specific Gravity of Bitumen: 1.025 Specific Gravity of Granite: 2.60

Coarse Agg: 42 %, 504 g Fine Agg: 50 %, 600 g Filler: 8 %, 96 g

Binder Content (%)	Sample No.	Height (mm)	Mass of specimen		Volume (cm^3)	Specific gravity		Air voids (%)		Flow (mm)	Stability (KN)		
			In air (g)	In water (g)		Bulk	Theory	Total mix	VMA		Measured	C.F.	Corrected
4.5	1	69.87	1270.5	702.5	568	2.16	2.36	8.4	20.68	1.05	4.21	0.86	3.62
	2	70.52	1245.5	646.0	599.5					1.11	5.4	0.78	4.21
5.0	1	71.23	1221.5	623	598.5	2.20	2.34	5.93	19.61	1.66	6.7	0.81	5.43
	2	70.01	1234.5	654	580.5					1.78	6.46	0.83	5.36
5.5	1	71.68	1229.5	639	590.5	2.23	2.33	4.13	18.91	2.03	8.25	0.81	6.68
	2	70.37	1246	657	589					1.99	8.18	0.81	6.63
6.0	1	69.95	1270.5	658	602.5	2.24	2.32	3.4	18.93	2.08	6.88	0.78	5.37
	2	69.74	1281.5	679	602.5					2.03	6.74	0.78	5.26
6.5	1	69.98	1285	692	593	2.20	2.28	3.5	19.67	2.2	5.69	0.81	4.61
	2	70.86	1230.5	693	537.5					2.16	4.93	0.93	4.59

Appendix B: Project Gantt chart

FYP 1

No	Task name/week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Initiation of project title														
2	Submission of project title														
3	Preliminary literature research														
4	Extended proposal submission														
5	Supplementary literature research														
6	Proposal defence														
7	Preparation of materials and preliminary data collection on materials														
8	Submission of Interim draft report														
9	Submission of Interim Report														

FYP 2

No	Task name/week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Tests on aggregates														
2	Preparation of bitumen and fillers														
3	Tests on bitumen and fillers														
4	Preparation of bituminous mixture samples														
5	Conducting marshal test on samples.														
6	Data analysis														
7	Submission of progress report														
8	Supplementary literature research														
9	Pre-SEDEX														
10	Submission of draft final report														
11	Submission of dissertation (soft bound)														
12	Submission of technical paper														
14	Viva														
15	Submission of project dissertation hard bound.														