THE EFFECT OF DIFFERENT AGGREGATE TYPES AND GRADATION ON THE CHARACTERISTICS OF BITUMINOUS MIXTURES

By

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FINAL PROJECT REPORT

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CERTIFICATION OF APPROVAL

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Approved:

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CERTIFICATION OF ORIGINALITY

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

Noraihan bt Md Yusoff

ABSTRACT

Mineral aggregate constitutes approximately 95% of hot-mix asphalt by weight. Thus it contributes a lot on the characteristic of bituminous mixtures. This study is to determine the effect of different aggregate types and gradation on the characteristics of bituminous mixtures. Granite and limestone are tested for aggregate suitability as highway construction material and each of them were employed to produce two aggregate gradations, which are well-graded and gap-graded. Lab tests were done to determine the characteristics of the bituminous mixtures of each combination. The results were compared with the specifications of the Jabatan Kerja Raya (JKR). From the result obtained, both granite and limestone are usable as highway construction material. However, granite is more recommended for highway purpose as it has higher strength and more durable compared to limestone. A well graded mixture is proved to be able to carry and spread load imposed on it better than a gap-graded mixture.

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

Aggregates are a major material for civil engineering construction. Production of aggregates for civil engineering work and building construction 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. 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.

All bituminous materials are basically a mixture of aggregate (coarse and fine), bitumen (of various grades), mineral filler and admixtures. The properties and uses of these mixtures will depend upon the proportions of the mixture. Mineral aggregate constitutes approximately 95% of hot-mix asphalt (HMA) by weight. The mineral aggregate is made up predominantly of coarse aggregate. As knowledge of the role played by aggregates in pavement performance increases, the importance of aggregate testing for quality and performance will continue to grow. Evaluation of aggregates in terms of fundamental physical and chemical properties is crucial to ensure quality and predict performance. The need to provide adequate procedures for testing aggregate quality will increase in the future as the use of recycled and waste material expands. These materials will need to be tested to ensure quality and pavement performance are not compromised.

There is also a need to evaluate the effect of aggregate gradation on the bituminous mixtures in order to avoid segregation and to obtain better workability for construction. An aggregate's particle size distribution, or gradation, is one of its most influential characteristics. In HMA, gradation helps determine almost every important property including stiffness, stability, durability, permeability, workability, fatigue resistance, frictional resistance and resistance to moisture damage (Roberts et al., 1996). Because of this, gradation is a primary concern in HMA mix design and thus most agencies specify allowable aggregate gradations. Dense or well-graded aggregate refers to a gradation that is near maximum density. The most common HMA mix designs tend to use dense graded aggregate. For gap graded aggregate, it refers to a gradation that contains only a small percentage of aggregate particles in the mid-size range. The curve is near-horizontal in the mid-size range. These mixes can be prone to segregation during placement.

The quality of materials shall conform to the standards and shall not include a deleterious amount of organic materials, soft particles, clay lumps and etc. The selection of materials, gradation, and bitumen content are important to obtain a mix with the desirable stability, durability, and skid resistance as well as good workability.

1.2 Problem Statement

Granite and limestone rocks are available in large quantity. It is recorded that little granite is used as construction aggregate in different parts of the world such as in Germany, Italy, Great Britain, etc. Malaysia also produces huge quantities of aggregates, of which the major share comes from limestone and granite, while the rest is comprised of basalt, diorite and gravel.

Moreover, as good proven aggregate supplies become depleted, it becomes increasingly important to be able to evaluate alternative sources especially with reference to testing for different rocks together with deleterious substances. Thus processing and testing are an important part of determining the quality of aggregate used. The basic principle of good aggregate processing is to obtain aggregate of the highest quality with the least cost.

Several studies were carried out in the past, concerning the properties of aggregates, especially of the aggregates of igneous origin and carbonated rocks. This study assesses the suitability of the use of granite and limestone as construction aggregates in bituminous mixtures. Mostly the facts employed will be laboratory based. This will assist in making decisions for the proper use of the granite and limestone as aggregate in future construction purposes which may provide better strength and ability to withstand wear.

1.3 Objectives

The objectives of this research are as follows:

i. To determine whether engineering properties of granite and limestone are adequate to be used as construction aggregates in bituminous mixtures.
ii. To study the effect of different aggregate gradation on the characteristics of bituminous mixtures.

1.4 Scope of Study

Although this project is in relation to the aggregate types and gradation, it still covers quite a large scope. The study will be narrowed down by focusing on two types of aggregates, which are granite and limestone, and gradation of well-graded and gap-graded materials. Four combinations of mixtures will be prepared, limestone was employed to produce two aggregate gradations (well-graded and gap-graded), and the same goes with granite.

The preliminary study will be focusing on determining the characteristics of aggregate sample in order to meet the requirement in terms of gradation, plastics characteristics and strength. It will also involve the test for asphaltic materials to determine their consistency and their quality to ascertain whether materials used in highway construction meet the specifications.

Lab tests also were done to determine the characteristics of each combination of bituminous mixtures. The characteristics to be determined include the specific gravity, void, flow, stability, stiffness and density of the bituminous mixtures. All of these criteria will be observe to determine the best combination of bituminous mixtures.

CHAPTER 2
LITERATURE REVIEW

2.1 Definitions

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, etc. (ASTM Designation D8-94). Aggregates are a component of composite materials such as concrete and asphalt concrete; the aggregate serves as reinforcement to add strength to the overall composite material.

Definitions:

(a) Coarse aggregate: 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 (ASTM Designation C 125-93).

(b) Fine aggregate: sand, an unconsolidated (loose), rounded to angular rock fragment or mineral grain having a diameter in the range of 1/1 to2 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).

(c) Open graded aggregate: An aggregate that has a particle size distribution such that when it is compacted, the voids between aggregate particles, expressed as a percentage of the total space occupied by the material, remain relatively large (ASTM Designation D8-94).

(d) Dense graded aggregate: An aggregate that has a particle size distribution such that when it is compacted, the resulting voids between the aggregate particles, expressed as a percentage of the total space occupied by the material, are relatively small (ASTM designation D 8-94).

(e) Gap grading: A particle size distribution in which particles of certain intermediate sizes are wholly or substantially absent.

(f) Continuous grading: A particle size distribution in which intermediate size portions are present as opposed to gap-grading.

(g) Concrete: A composite material that consists essentially of a binding medium within which are embedded particles or fragments of aggregate; in hydraulic-cement concrete the binder is formed from a mixture of hydraulic cement and water, (ASTM Designation C 125-93).

2.2 Description of Igneous Rock

2.2.1 General

Igneous rocks comprise approximately 95% of the upper 16 km of the earth's crust. They can be sources for aggregates due to their high strength, durability and resistance to weathering. There are two major types of igneous rocks, extrusive and intrusive. Extrusive rocks include those igneous rocks that reached the earth's surface in a molten or partly molten state, such extrusive or volcanic rocks tend to cool and crystallize rapidly. The result is that their grain size is generally small. Intrusive or plutonic rocks are the result of crystallization from a magma deeply buried in the earth's crust. This magma generally cools slowly and the mineral constituents crystallizing from it have time to grow to considerable size, giving the rock a medium to coarse grained texture. When magma intrudes as dikes (discordant tabular bodies) the textures are usually finer grained than those of massive plutonic rocks but coarser than those of volcanic rocks.

2.2.2 *Engineering Properties of Granite*

2.2.2.1 Composition of Granite

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 a significant amount of its desirable durable properties. The quartz will appear gray, but is actually colorless and is reflecting and fusing the colors of the white and black minerals surrounding it.

The chemical composition of granite is typically 70-77% silica, 11-13% alumina, 3-5% potassium oxide, 3-5% soda, 1% lime, 2-3% total iron, and less than 1% magnesia and titania, as tabulated in Table 1. Volcanic rock of equivalent chemical composition and mineralogy is called rhyolite. Granites are the most abundant plutonic rocks of mountain belts and continental shield areas.

Table 1: Chemicals Composition of Granite

Item	Percentage (%)
Silica	70-77
Alumina	11-13
Potassium Oxide	3-5
Soda	3-5
Iron	2-3
Lime	1
Magnesia and Titania	< 1

2.2.2.2 Physical Characteristics of Granite

Granite is an acid crystalline igneous rock with an average specific gravity of 2.66. A cubic meter of granite weighs on the order of 2.66 tons or almost two tons a 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.

2.2.2.3 Mechanical Properties of Granite

Granite has a significantly high average strength which can be explained by its petrography. Johnson and Degraff (1988) explained that, crystal size is the primary strength factor in granite. 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. Dearman et al. (1978) tabulated the range of compressive strength for different weathered states of granite:

Fresh > 250 MPa
Discolored 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.

2.3 Description of Sedimentary Rock

2.3.1 General

Sedimentary rock is one of the three main rock groups (the others being igneous and metamorphic rock). Rock formed from sediments covers 75-80% of the Earth's land area, and includes common types such as chalk, limestone, dolomite, sandstone, conglomerate and shale. Sedimentary rocks are classified by the source of their sediments, and are produced by one or more of:

- Clastic rock formed from fragments broken off from parent rock, by
  - Weathering in situ or
  - Erosion by water, ice or wind, followed by transportation of sediments, often in suspension, to the place of deposition;
- Biogenic activity; or
- Precipitation from solution.

The sediments are then compacted and converted to rock by the process of lithification.

2.3.2 Engineering Properties of Limestone

2.3.2.1 Composition of Limestone

Limestone is made up of varying proportions of following chemicals with calcium and magnesium carbonate being the two major components, as shown in Table 2.

Table 2: Chemicals Composition of Limestone

Item	Percentage (%)
Calcium carbonate, $CaCO_3$	98
Magnesium carbonate, $MgCO_3$	1.08
Silica, SiO_2	0.32
Alumina, Al_2O_3	0.08
Iron oxide, Fe_2O_3	0.06

The two main impurities are silica and alumina with iron as the third.

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.

2.3.2.2 Physical Characteristics of Limestone

The color 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 formity, and crystal arrangement. For lime production purposes there are two factors related to limestones 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 crystal size, 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 most cases soft enough to be scratched with a knife. Marbles and travertines have the highest compressive strength whilst chalk has the lowest.

Due to the variance in porosity, the bulk densities of various limestones 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 limestones and 2.75-2.9 for dolomitic limestones. Chalk has a specific gravity of between 1.4 and 2.

2.4 Effect of Aggregate Grading

Grading is an important factor that affects workability. The basic purpose of gradation is to reduce the effect of undesired particle size and to assure high quality aggregate production. While using aggregate with good grading, a reasonable workability and minimum segregation should be obtained in order to produce a strong and economical bituminous mix. Aggregate particles can well pack if the next size of particle is small enough so that it can penetrate inside voids. Thus, aggregates slightly differing in size cannot be used side by side. Following is a summary of the highlights of studies related to the effect of aggregate gradations on the properties of bituminous mixture.

Herrin and Goetz (1954) expressed that the mixture of one-size grading had the lowest strengths regardless of the aggregate shape used. The greatest strength was produced by dense graded aggregates. The strengths of open-graded mixtures were less than those of the corresponding dense-graded ones but were greater than mixtures of one size-grading. The differences in strength between the mixtures with three type of grading were due primarily to difference in values for cohesion but not due to differences in the angle of internal friction.

Lees and Kennedy (1975) mentioned that the denser the grading of an aggregate, the less the crushing occurs. Bartley (1980) preferred maintaining a uniform distribution of particles to provide maximum particle surface area in contact and to leave minimum space between the particles. Grading should provide adequate permeability to ensure drainage.

Sonderegger (1961) showed that oversanded gradations are also very sensitive to the presence of residual water in the mixes during laydown. His study indicated that the residual moisture content was about 0.3% or less.

Lee (1970) has discussed the variation of the aggregate gradation on properties of mixes, while Huang (1970) combines gradation effects and shape effects in his study by using a gradation index and a particle index. He found a large influence of gradation and shape of the aggregate on the properties of the mixes. They were evaluating the effect of aggregate properties on the change in volume and principle stresses differences with changes in axial deflection in triaxial compression tests. Huang also suggests that gradation should be further studied in order to get high stability mixes with sufficient voids in mineral aggregate (VMA) to allow sufficient asphalt binder.

CHAPTER 3
METHODOLOGY

The potentials of the granite and limestone as construction aggregates for highway construction were assessed through several processes. Specimens for all tests were prepared from the collected aggregate samples according to the specifications for respective tests. For the preliminary stage of the study, lab test were 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. The tests that will be conducted are summarized in Table 3.

3.1 Determination of the Aggregate Properties

3.1.1 Physical Properties

3.1.1.1 Specific Gravity and Water Absorption Test

Specific gravity of an aggregate was 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 taken was first dried and immersed in water for 24 hours. It was then removed from the water and surface dried. The saturated surface dried sample was weighed.

Table 3: Tests for Aggregates, bitumen, filler and design mix.

Material		Test	Objective
AGGREGATE (coarse and fine)	PHYSICAL PROPERTIES	Particle Density (Specific Gravity) and Water Absorption	To measure the particle density and water absorption of aggregates.
	MECHANICAL PROPERTIES	Aggregate Abrasion Test (Lost Angeles Test)	To determine the aggregate abrasion value (AAV) in order to evaluate the east or difficulty with which aggregate particles are likely to wear under attrition from traffic.
		Aggregate Impact Value Test	To evaluate the toughness or resistance of the aggregate to fracture under repeated impacts.
BITUMEN		Standard Penetration Test for Bitumen	To determine the penetration of semi-solid and solid bituminous materials.
		Ring and Ball Test (Softening Point)	To determine the softening point of bituminous binder.
		Ductility Test	To determine the basic cohesive strength of bitumen.
		Particle Density (Specific Gravity)	To measure the specific gravity of bitumen.
FILLER		Particle Density (Specific Gravity)	To measure the specific gravity of filler.
DESIGN MIX		Marshall Test	To measure the loss of cohesion resulting from the action of water on compacted bituminous mixtures containing asphalt cement.

The saturated surface dried sample was immediately placed in container and its weight in water was determined. Finally, the sample was oven dried and weighed a third time. Then,

Particle density on an oven-dried basis= D/ A- (B-C) (3.1)

Particle density on a saturated and surface-dried basis= A/ A- (B-C) (3.2)

Apparent particle gravity = 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) = 100 (A-D) / D (3.4)

3.1.2 Mechanical Properties

3.1.2.1 Los Angeles Abrasion Test

It is required to find the amount of wear of aggregate used in construction work. For this purpose, Los Angeles test was carried out according to ASTM Designation: C 131-89. This test was performed to determine the abrasive resistance of aggregate by abrasion and impact. The principle of this test was 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 was evaluated by the test.

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. Suggested maximum Los Angeles abrasion values were 40 for bituminous materials and 50 for concrete aggregates. Typical Los Angeles abrasion value for coarse aggregate is 20% or lower. For softer aggregate such as limestone, Los Angeles abrasion value is about 50% or higher. Aggregates with abrasion value over 50% are not suitable for road pavements. Determination of Los Angeles abrasion value as follows:

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

Where;

M_1 = Mass of aggregate retained on No. 4 ASTM sieve (kg)

M_2 = Mass of material passing No. 12 ASTM sieve (kg)

3.1.2.2 Aggregate Impact Value Test

This test was performed to evaluate the toughness or resistance of the 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 (1975) was followed 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 was filled in cylindrical measure in three layers by tamping each layer by 25 blows. It was transferred from the measure to the cup of the aggregate impact testing machine and compacted by single tamping of 25 strokes. The hammer was 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 was sieved on 2.36 mm (no.8) sieve. The aggregate impact value was then expressed as the percentage of the fine formed in terms of the total weight of the sample taken.

$$AIV = [(w_1 - w_2)/w_1] \times 100 \qquad (3.6)$$

Where,

w_1 = weight of original sample,

w_2 = weight of sample coarser than 2.36 mm (no.8) sieve.

3.2 Determination of the Bitumen Properties

3.2.1 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 millimeter 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.

3.2.2 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, as shown in Figure 1. A steel ball is placed upon the bituminous material; the water is then heated at the rate of 5 deg C 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.

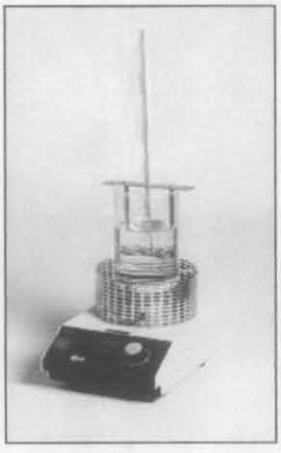

Figure 1: Ring and ball apparatus

3.2.3 Ductility Test

Ductility is defined as distance in cm to which a standard briquette of bitumen can be stretched before the thread breaks. The briquette is stretched at a rate of 50 mm /min. +/2.5 mm per minute at a temperature of 27°C +/0.5°C.

The apparatus as shown in Figure 2 consists of water bath with a thermostatic heater and a circulating pump to maintain uniform water temperature. One half of the briquette moulds is fixed on a fixed plate in the water bath, the other half of the briquette mould is fixed to a carrier which slides over a rotating the threaded shaft with a clutch. The motor and gears to rotate the shaft are housed in a cabinet fixed above the other end of the bath. A pointer fixed to the carrier moves over a scale graduated from 0-110 cm x 1 mm fixed on the bath with "0" (Zero) of the scale towards the fixed plates side. The rotating shaft has 2 speeds of travel for the bracket, 5 cm/min and 1 cm/min. selected by a clutch.

Water bath inside is aluminium/steel, it is an insulated water bath. Water bath is provided with a drain. A heater with thermostatic control is fixed inside the water bath. Control switches for motor pump heater and indicator lamps are fixed at a convenient place on the water bath. Complete with three briquette moulds and one base plate, steel all made of brass operates on 230V A.C. supply single phase.

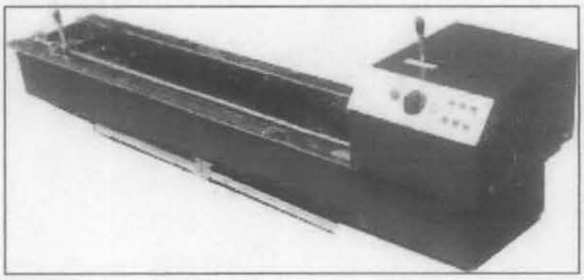

Figure 2: Ductilometer- Ductility Testing Apparatus.

3.2.4 Specific gravity for Bitumen

In order to get the specific gravity of bitumen, the experiment is conducted by using pycnometer. First, a 600 ml Griffin low form beaker was filled with distilled water. The beaker was then put inside the water bath. Weight of the pycnometer was taken (Mass A). The beaker was then removed from the water bath, and the pycnometer was filled with distilled water and placed in the beaker. Both of them were put in the water bath. The weight of the pycnometer and water were then taken (Mass B). Sample inside the pycnometer was poured about 3/4 and left to be cooled. Once again, the weight of the pycnometer and sample were taken (Mass C). Distilled water was added inside the pycnometer and put into the beaker. After 30 min, the weight of the pycnometer was taken (Mass D).Then the particle density was calculated.

3.3 Determination of the Filler Properties

The specific gravity of filler is determined by using Ultrapycnometer 1000, Figure 3. 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 into the cell.

Figure 3: 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. For well gradation, 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 mold 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 molds and left to cool down before starting the bulk specific gravity (Gmb) test: ASTM D2726 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 granite with gap gradation and also limestone with both gradations. For gap-graded, there are also five percentages of the asphalt prepared; 6.0%, 6.5%, 7.0%, 7.5%, and 8.0%.

3.5 Materials Preparation

There are two aggregate gradations employed for this project, well and gap gradation. The gradation of the combined coarse and fine aggregates, together with ordinary Portland cement added as an adhesion and anti-stripping agent for well and gap gradations are as shown in Table 4;

Table 4: Percentage for Coarse, Fine, and Ordinary Portland cement for Well and Gap Gradations

Material	Well Gradation	Gap Gradation
Coarse Aggregate	42%	35%
Fine Aggregate	50%	55%
Filler (OPC)	8%	10%

In order to obtain the necessary gradation, sieving analysis was done to separate the required sizes. Aggregate from each sieve size is then weighted to obtain total aggregate weight of 1.2kg. Well gradation for coarse aggregate shall conform to the appropriate envelope by JKR shown in Table 5.

Table 5: Well Gradation Limits for Asphaltic Concrete

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

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

The gap gradation for coarse aggregate is based on Table 6.

Table 6: Detailed Aggregate Gradation of the Material Used for Gap gradation

BS Sieve Size	Coarse Agg. (35%)	Fine Agg. (55%)	Filler (10%)	Total
20.00 mm	35	55	10	100
14.00 mm	31.44	55	10	96.44
10.00 mm	5.79	55	10	70.79
6.300 mm	0.36	55	10	65.36
5.000 mm	0.17	54.63	10	64.80
2.360 mm	0.09	53.83	10	63.92
0.600 mm	-	51.60	10	61.60
0.300 mm	-	21.88	10	31.88
0.212 mm	-	13.16	10	23.16
0.125 mm	-	-	9.99	9.99
0.090 mm	-	-	9.96	9.96
0.075 mm	-	0.81	9.85	10.66
0.063 mm	-	-	9.42	9.42
0.045 mm	-	-	0.85	0.85

Source: The Properties and Performance of Polymer Fiber Reinforced Hot-Rolled Asphalt.

3.6 Marshall Testing Machine

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 binder are determined and compared to specifications. The optimum bitumen content will be compared to determine the best aggregate and gradation for bituminous mixtures.

Figure 4: Marshall Testing Machine

3.7 Health, Safety and Environment (HSE) Analysis

Labs are inherently dangerous working environments. Procedures performed and materials utilized require serious concern to ensure a safe and healthy working environment for personnel. Understanding the hazards and the risks they present is an essential foundation for achieving excellence in environment, health, and safety performance.

Hazards identify within the highway lab is mostly physical hazard, which are include the noise, exposure to heat and dust. Noise can come from equipment in the lab. Although the sound produced might not loud enough, but too much noise exposure may cause a temporary change in hearing or a temporary ringing in ears. However, the short-term problems will go away in a few minutes or hours after leaving the noise. Heat can be produced from the oven and dust result from processes such as aggregate sieving or compaction.

Studies by NIOSH also had shown that acute toxic effects of exposure to asphalt to human health. They were irritation of the serious membranes of the conjunctivae and the mucous membranes of the respiratory tract [NIOSH 1977a]. For any test performed in the lab, several safety measures are taken in order to avoid any accident that can cause harm. Therefore hearing protectors are recommended to avoid the effect of noise, and great care should be exercised when handling the hot material and equipment. This include wearing gloves and also appropriate respiratory protection while conducting asphalt material for the test.

CHAPTER 4
RESULTS AND DISCUSSIONS

Lab tests were done in order to obtain the physical and mechanical properties of aggregates, properties of bitumen, and filler. These data are important to ensure that the materials used for the project are according to the standard set by JKR.

4.1 Physical Properties of Aggregates

Two tests were done to investigate the physical properties of granite and limestone, which are Particle Density (Specific Gravity), and Water Absorption.

4.1.1 Aggregate Particle Density (Specific Gravity) & Water Absorption

Specific gravity is defined as the ratio of the unit weight of aggregate to 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.

Table 7: Particle Density and Water Absorption value for coarse and fine aggregate.

Properties	Coarse Aggregate		Fine Aggregate
	Granite	Limestone	
Specific Gravity	2.56	2.50	2.581
Water Absorption (%)	1.10	3.17	0.508

Table 7 shows the result of particle density and water absorption of both coarse and fine aggregates. The specific gravity of fine aggregate sample is 2.581. Specific gravity for granite is 2.56, slightly higher than limestone which is 2.50. From the result, it is clearly shown that granite is denser than limestone. This might due to the structure of the aggregate itself. 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. This situation results in higher density of granite. However, limestone consists of high porosity as the result of sedimentation process during the rock formation.

Water absorption value of the sand sample is 0.508. JKR Manual on Pavement Design has specified that requirement for water absorption for coarse and fine aggregate should not more than 2%. The value is below 2%, thus it is suitable to be used in the bituminous mixtures design. Granite also has water absorption within the requirement, which is 1.10. However, limestone shows higher water absorption value, and it is exceeding the JKR specification. Water absorption is also closely related to porosity. As the sample immersed in water bath, water will fills in the pore spaces within the rock. It is known that aggregate with higher water absorption value are porous and thus weak. So from the water absorption value obtained, it can be concluded that limestone has higher porosity and weaker than granite.

4.2 Mechanical Properties of Aggregates

There are two tests needed on examining the mechanical properties of granite, which are Aggregate Abrasion Test and Aggregate Impact Value Test. The Los Angeles abrasion test is carried out in a sample of aggregate all retained on the No. 4 ASTM sieve. The result of the test is expressed as the percentage by mass of material passing a No.12 ASTM sieve after test.

For Aggregate Impact Value Test, the effect due to the regular impact to determine the toughness of aggregate was carried out by this test. The percent loss was determined by knowing the weight of aggregate less than 2.36 mm that was produced by impact during the test.

4.2.1 Aggregate Abrasion Value (Los Angeles Abrasion Test)

The test was performed to determine the effect of the abrasion, attrition process and the pounding action of the steel balls on aggregate. Unfortunately, the test does not seem to correspond well with field measurements (especially with slags, cinders and other lightweight aggregates). Some aggregates with high L.A. abrasion loss, such as soft limestone, provide excellent performance.

Both granite and limestone were tested for Los Angeles Abrasion Test. The results are as shown in Table 8 and 9. Abrasion value for granite is 18% and for limestone is 52%.

Table 8: Result for Aggregate Abrasion Value Test for granite.

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

Table 9: Result for Aggregate Abrasion Value Test for limestone.

			Test1
Mass of aggregate retained on No. 4 ASTM sieve,	M_1	kg	5.0
Mass of material passing No. 12 ASTM sieve,	M_2	kg	2.6
Los Angeles abrasion value $\frac{M_2}{M_1}$ x 100%		%	52

The result shows that abrasion value for granite is lower than limestone. This indicates that granite is more durable and can resist crushing under the roller better than limestone. The abrasion value under JKR requirement for coarse aggregate is it must not more than 60%. Both values still satisfy the requirement even though the value for limestone is quite high. However, aggregate with high L.A. abrasion loss values will tend to create dust during production and handling, which may produce environmental and mixture control problems.

4.2.2 Aggregate Impact Value Test

Altogether 2 tests were performed for each type of aggregate. The results are presented in Table 10 and 11. The mean aggregate impact value for granite was 23.9%. The mean aggregate impact value for limestone was 25.39%.

Table 10: Result for Aggregate Impact Value Test for limestone.

		Test No.	
		1	2
Nett weight of the aggregate in the measure (A)	(g)	919.59	890.00
Weight of sample coarser than 2.36 mm (no.8) sieve. (B)	(g)	684.17	666.00
Weight of sample retained in the pan. (C)	(g)	235.42	224.00
Aggregate Impact Value (AIV)	(%)	25.6	25.17

Table 11: Result for Aggregate Impact Value Test for granite.

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

The mechanical properties of both granite and limestone varied reflecting their strength properties. The typical impact value possible for granite is ranges from 9 to 35, and the typical value for limestone is ranges from 17 to 33 (Refer Appendix A). Thus both values lay on the allowable ranges. The test indicates that granite strength is higher than limestone as lesser percentage of crushed aggregate recorded. Table 12 shows the comparison between all the aggregate properties discussed before with JKR requirements.

Table 12: Comparison between Aggregate Properties and JKR Requirements

Properties	Coarse Aggregate		Fine Aggregate	JKR Requirements
	Granite	Limestone		
Specific Gravity	2.56	2.50	2.58	-
Water Absorption (%)	1.10	3.17	0.51	Not more than 2
Abrasion Value (%)	18.00	52.00	-	Not more than 60
Impact Value (%)	23.9	25.39	-	9 to 35 (Granite) 17 to 33(Limestone)

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, four tests are allocated. The tests are Ductility Test, Standard Penetration Test, Ring and Ball Test (Softening Point), and Particle Density Test (Specific Gravity).

4.3.1 Ductility Test

Ductility is defined as distance in cm to which a standard briquette of bitumen can be stretched before the thread breaks. The briquette is stretched at a rate of 50mm/minute ±25mm per minute at a temperature of 27°C ± 0.5°C. Altogether two sets of samples were tested. The results of the ductility test are presented in Table 13. The average ductility value found was 112.25cm.

Table 13: Result for Ductility Tests.

DUCTILITY TEST: ASTM D113			
Sample No.	**Mould No. 1**	**Mould No. 2**	**Mean**
A	103 cm	121.5 cm	**112.25cm**

In flexible pavement construction, bitumen binders are used. It is important that bituminous material forms ductile thin film around the aggregates, which serves as a binder. The binder material not of sufficient ductility renders pervious pavement surface and leads to development of cracks. Therefore it is important to carry out the ductility tests on bituminous material. The result obtained shows ductility value of 112.25cm. The standard JKR value for ductility at 25°C shall not less than 100cm (Manual on Pavement Design). So, it can be summarized that the result obtained comply the requirement.

4.3.2 Softening Point Test

Softening point test was performed to determine the softening point of bituminous binder. A total of 2 samples were tested. The results of the test are presented in Table 14.

Table 14: Result for Softening Point Tests.

SOFTENING POINT TEST BS2000: Part 58; 1983/ ASTM D36*			
Sample No.	**Ball 1**	**Ball 2**	**Mean**
A	52.4°C	52.6°C	**52.6°C**
B	48.0°C	48.6°C	**48.3°C**

The result obtained shows two mean values, which 52.6°C and 48.3°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 large 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.

4.3.3 Standard Penetration Test

Penetration test measure 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 Table 15.

Table 15: Result for Standard Penetration Test

STANDARD PENETRATION TEST -BS2000: Part 49: 1983/ ASTM D5				
Temperature: 25°C		Load: 100 g		Time: 5 sec
Sample No.	Determination 1	Determination 2	Determination 3	Mean
A	88	88	85	87
B	86	86	84	85

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 86. According to bitumen properties by JKR, standard penetration value must be between 80 and 100 (for penetration grade 80-100). Thus the bitumen that will be used for the later part of the study fulfills the requirement by JKR in term of standard penetration.

4.3.4 Specific Gravity Test

The experiment is conducted by using pycnometer. A total of 2 samples were tested and the results are as shown in Table 16. The average specific gravity value is 1.03. This value complies with the standard specific gravity value for bitumen, which is between 1.02 and 1.04.

Table 16: Result of Specific Gravity for Bitumen.

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

Relative density = (C – A)/ [(B – A) – (D – C (4.1)

Density = Specific gravity × W_T

Where W_T = density of water at the test temperature

Table 17 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 17: Comparison between Bitumen Properties and JKR Requirements

Properties	Bitumen Grade 80-100	JKR Requirements
Specific Gravity	1.03	Between 1.02 and 1.04
Ductility (cm)	112.25	Not less than 100
Standard Penetration (1/100 cm)	86	Between 80 and 100
Softening Point (°C)	48.3	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 (Appendix B).

Weight = 3.78 gram

Table 18: Specific Gravity Test for OPC.

Run	Volume (cm^3)	Density (g/cm^3)
1	1.14	3.32
2	1.14	3.31
3	1.13	3.34
4	1.13	3.33
5	1.14	3.33
6	1.14	3.31
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 18, the average specific gravity value of OPC is 3.32.

4.5 Properties of Bituminous Mixture

60 samples of bituminous mixtures with different aggregate types and gradation were prepared. The samples were then being tested using the Marshall Testing Machine to get the Marshall stability and flow.

The first step in the analysis of the results is the determination of the average bulk specific gravity for all test specimens. The average unit weight of each mixture is then obtained by multiplying its average specific gravity by the density of water γ_w. Others properties of the mix also calculated such as VMA (% voids in compacted mineral aggregates) and also porosity. (Refer Appendix C)

Graph of the following variables vs. binder content were plotted;

- Stability
- Flow
- Density
- VMA (% voids in compacted mineral aggregates)
- Porosity (% air voids in compacted mixture)

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

4.5.1 Analysis of the Marshall Test results

A graph of Marshall Stability, flow, density, VMA and porosity of all the mix are plotted as shown in Figure 5, 6, 7, 8 and 9. Comparisons of each variable for each mixture are discussed further in this part.

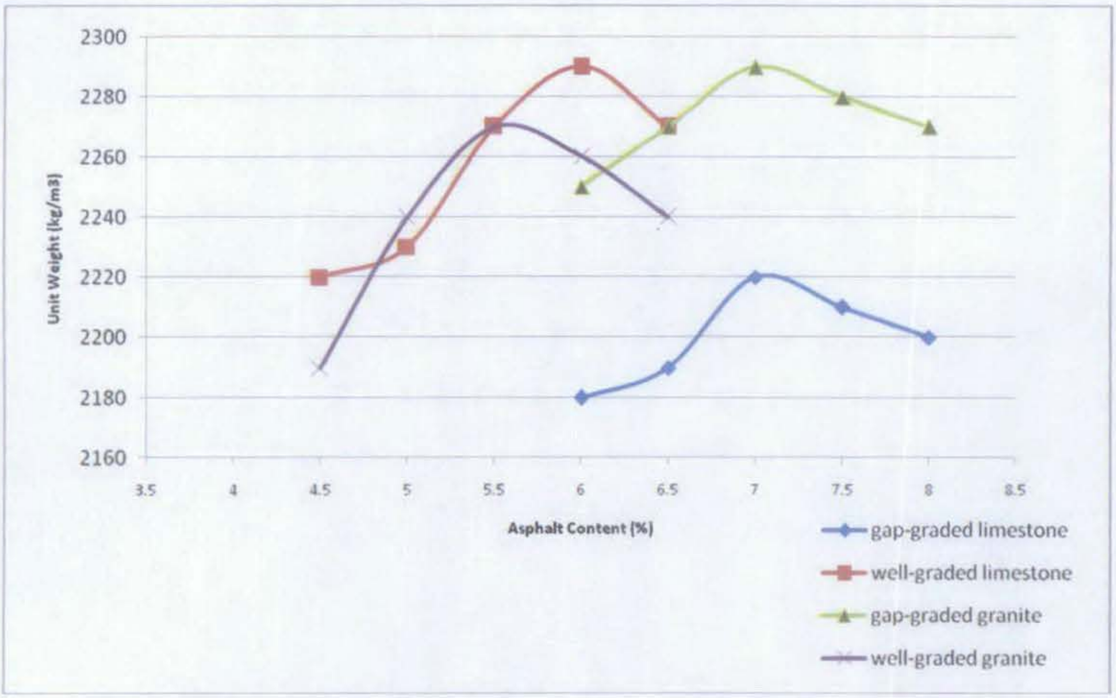

Figure 5: Unit Weight versus Asphalt Content

The value of unit weight or bulk density of the sample is determined by weighting the sample in air and in water. Each value is determined by calculating the average value for the specimens with the same asphalt content. Figure 5 shows the unit weight or density curves for each bituminous mixture. Well-graded granite was expected to has the highest value of unit weight. However, from the experimental result, well-graded limestone and gap-graded granite have higher values.

The samples were compacted using Marshall compactor. Limestone which has low strength tend to be crushed during the compaction process. For limestone of well gradation, the aggregate in the mid size range and bigger will be crushed, added to the existing finer sizes taggregate. All the smaller sizes aggregate will eventually filling the voids inside the mixture thus leads to low porosity. So during weighting the sample in water, the weight of this sample will become higher than the other sample with high porosity. This will lead to higher unit weight or density of the limestone mixture.

For the limestone with gap gradation, the unit weight is the lowest, eventhough the aggregate was also crushed during the compaction. This is because, the aggregate that crushed were consisted of bigger sizes only, as there is none or a very little amount of aggregate in medium size-range. As the bigger sizes aggregate crushed, it contribute to the aggregate in the middle size range, with the same amount of finer aggregate in the mixture. The mixture still has high porosity as the finer aggregate is not as much as in the well gradation to fill in the voids. It can be conclude that compaction does not have a very significant effect on the porosity and also unit weight of this mixture.

Granite with gap gradation has higher unit weight or density compared to well- gradation. The reason is because, gap gradation contain higher percentage of finer aggregate compared to well gradation. The more finer aggregate will lead to lower porosity of the mixture. The compaction process does not effect the sizes of the granite as it has greater strength. As the compaction process using the Marshall compactor is affecting the properties of the weak aggregates such as limestone , other means of compaction should be apply. For example, gyratory compactor.

In order to select the optimum percentage of binder content of each mixture, bitumen content corresponding the highest value of unit weight should be taken into consideration and will be calculated as the average with other variables.

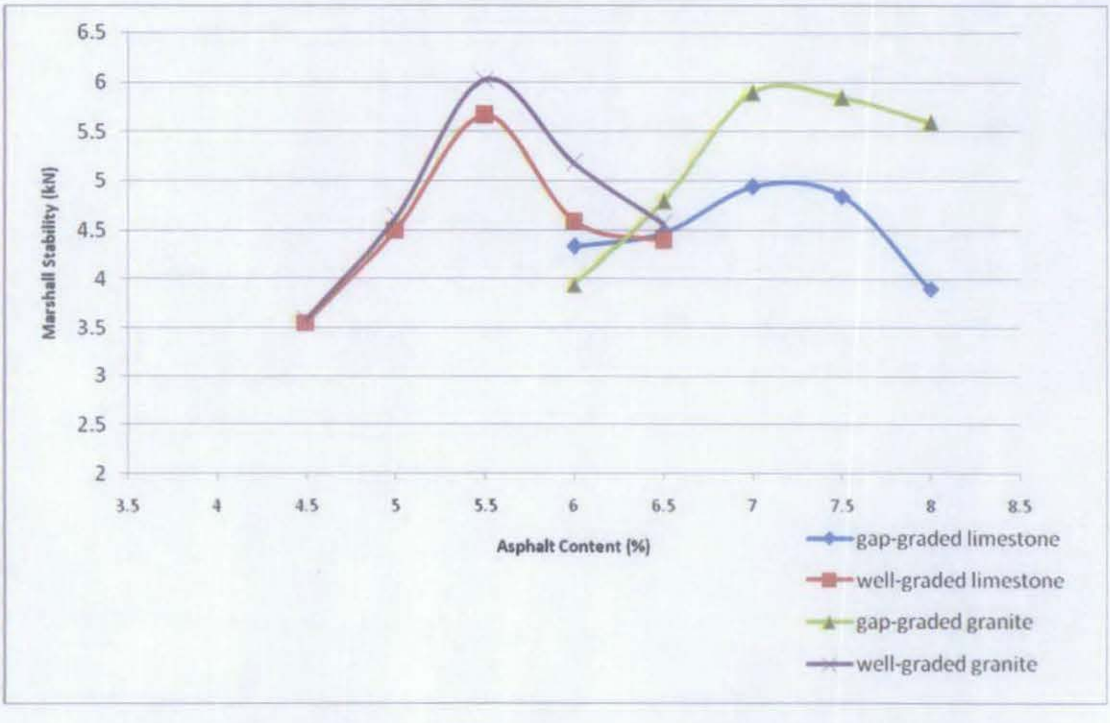

Figure 6: Marshall Stability versus Asphalt Content

Figure 6 shows the Marshall stability curves for each combination of bituminous mixture. The values were obtained directly from the Marshall Testing Machine. However the value should be corrected by multiplying by a certain correction factor based on the height of the sample. Marshall stability show the maximum load the sample can sustained before it failed. Stability of well-graded granite shows the highest value among others. This means that the mixture has higher strength compared to other samples.

The strength of granite contribute to the strength properties of its mixture. The gradation also plays an important roles because the gap gradation less strong than well gradation. It is proved from the experiment that both stability of well-graded granite and limestone are stronger than gap-graded sample of the two aggregates. These results were aligned with the result of aggregate impact value and LA abrasion of granite and limestone during FYP1. For the purpose of obtaining the optimum bitumen content for each sample, the percentage of bitumen content corresponding to the highest value of stability were taken.

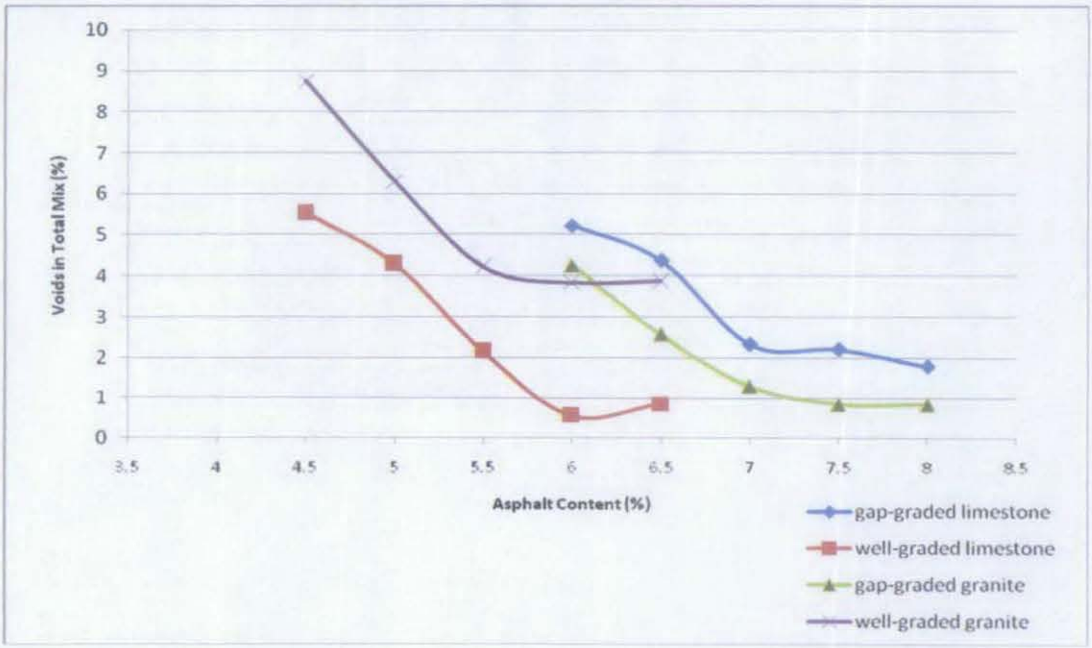

Figure 7: Voids in Total Mix versus Asphalt Content

Figure 7 shows percent of voids in total mix versus asphalt content. Percent air voids in compacted mixture is the ratio between the volume of the small air voids between the coated particles and the total volume of the mixture. Voids in total mix indicates the porosity of the mixture. As explained in the discussion of unit weight or density, the mixture of well- graded granite has higher porosity as it contain lower percentage of finer aggregate. A lesser amount of smaller aggregates are available to fill the voids in the mixture. For well-graded limestone, it has lower porosity as more finer aggregate produced during the compaction process.

In order to get the average optimum bitumen content, asphalt content is selected corresponding to air voids of 4%. It is the mean limits of 3% and 5%, the typical values for porosity of mixture.

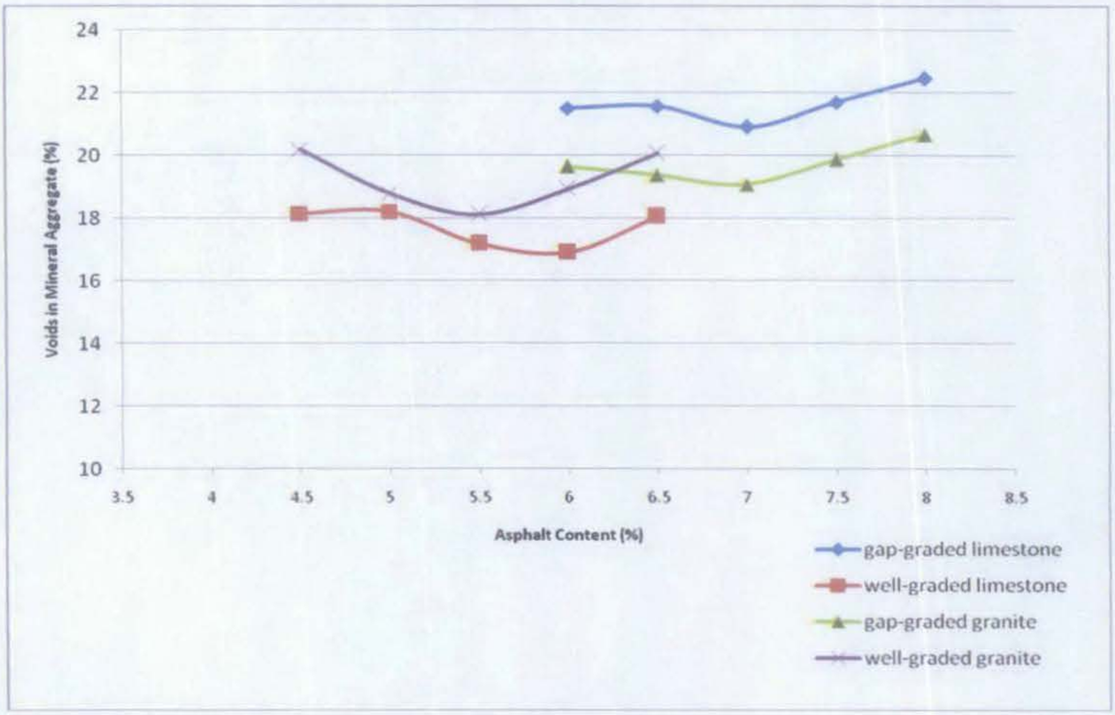

Figure 8: Voids in Mineral Aggregate versus Asphalt Content

The percent voids in compacted mineral aggregates, or VMA, is the percentage of void spaces between the granular particles in the compacted paving mixture, including the air voids and the volume occupied by the effective asphalt content. As shown in the Figure 8, well-graded limestone has the lowest VMA as the effect of compaction by the Marshall compactor. Limestone with gap gradation shows the highest VMA of all. This means that there are plenty of voids in the mineral aggregate itself. However for granite, the VMA for both gradation is quite similar, with well gradation slightly lower voids compared to gap gradation.

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

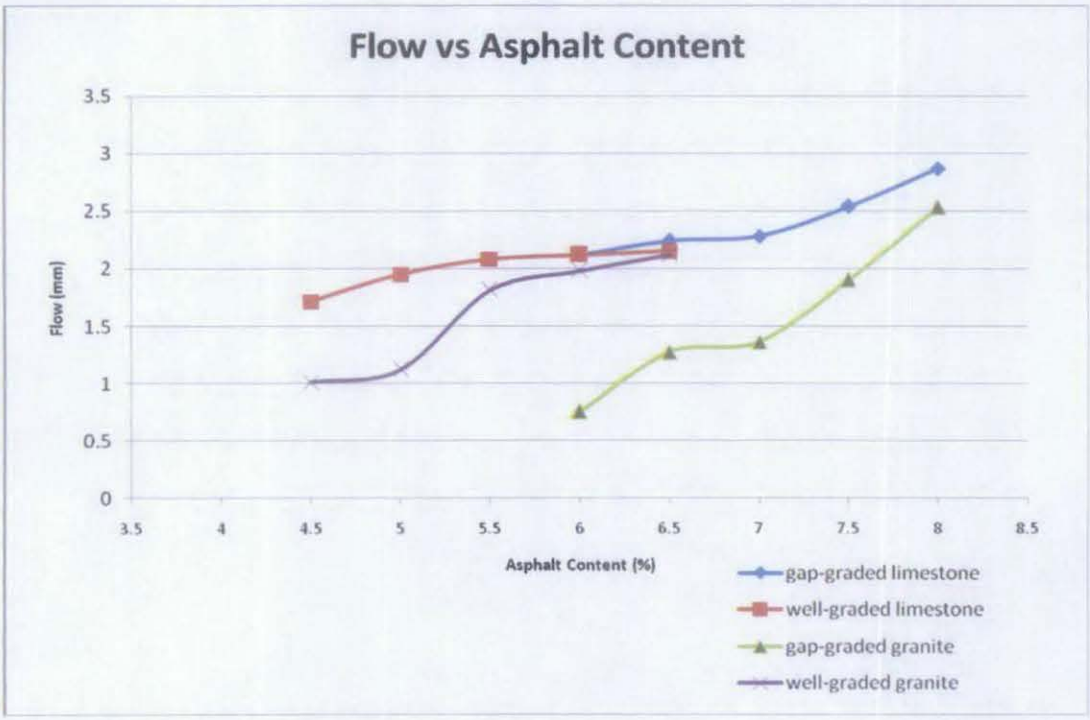

Figure 9: Flow versus Asphalt Content

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 9, it is shown that as the bitumen content in the mixture increased, the value of flow increased. Bituminous mixture of limestone with gap gradation shows highest value of flow or deformation. This is because, gap-graded limestone mixture requires more bitumen content compared to other mixture. The graph of flow does not considered in determining the optimum bitumen content of the mixture.

4.5.2 Mix Design requirement

The bituminous mixtures are designed in accordance to the Standard Marshall Test method. An average of optimum binder content (OBC) was obtains from stability, density, voids in total mix and VMA graphs. Table 19 shows the summary of optimum binder content for each combination of bituminous mixture shown in Appendix D.

Table 19: Optimum Binder Content for each bituminous mixture

Bituminous Mixture	Optimum Binder Content (%)
Granite (gap-graded)	6.80
Granite (well-graded)	5.55
Limestone (gap-graded)	7.00
Limestone (well-graded)	5.63

The properties of the mixtures were compared with the mix design requirement by JKR. The value of each property is taken at corresponding optimum bitumen content and compared with the JKR requirement, as shown in Table 20.

Table 20: Comparison between Properties of Design Mixes and JKR Requirements

Quality	JKR Requirement for Wearing Coarse	Well-graded granite at 5.55% BC	Gap-graded granite at 6.80% BC	Well-graded limestone at 5.63% BC	Gap-graded limestone at 7.00% BC
Stability (kg)	Not less than 500	600	550	550	494
Flow (1/100 cm)	20-40	18.5	13.0	21.0	22.8
Voids in the total mix (%)	3-5	4.1	1.7	1.6	2.3

The JKR requirements specify that the stability for a sample should not less than 500kg. According to Table 20, values for stability for all the samples are exceeding 500kg, except for mixture of limestone with gap gradation. The mixture has the stability value of 494kg, 1.2% lower than acceptable value. It means that the mixture containing limestone with gap gradation has lower strength and it is not recommended to be used as the pavement material. The low strength of the mixture is contributed from the gradation and also from the aggregate itself. Gap gradation provides low strength because there are lots of air voids inside the mixture which can be very unstable when the sample is loaded.

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. Comparing the values of stability of each mixture, it is clearly shown that mixture with well gradation has the highest stability. If considering in term of aggregate type, we can see that granite provides higher stability value compared to limestone. Granite itself is proven to have higher strength based on the AIV and LA test done in the earlier stage of the project.

The second criterion to be compared with the JKR requirement is flow, which is measured as the highest deflection at the peak load in increments of 0.01 in. It is specified that the flow value should be between 20-40/100cm. Flow has to be in the allowable range so that the mixture did not suffer various problems. High flow value indicates a plastic mix that will experience permanent deformation under traffic. Low flow value may indicate a mix with higher than normal voids and insufficient asphalt content for durability, and also a mix that may experience premature cracking due to brittleness. From the result obtained, it is clearly shown that the flow values for both mixtures of granite have low flow as compared to the allowable range. However, for well-graded granite mix, the value do not varies too much from the specified value.

The percentage of voids in the total mix (VTM) also compares with JKR specifications. It is stated that the value of VTM should lie between 3-5%. Low VTM minimizes possibility that water gets into the mix, penetrate thin asphalt film and strip the asphalt cement off the aggregates. However, in construction, the in-place VTM should initially be slightly higher that 3-5% to allow for some additional compaction. Comparing the four mixtures in term of percentage of voids in the total mix, only mixture with well-graded granite shows value within the allowable range. Other mixtures have very low voids, since those mixtures contain high percentage of finer aggregate that fills in the voids.

The best combination of aggregate types and gradation is denoted by the lowest value of optimum binder content. Based on Table 19, granite with well gradation shows the lowest OBC among the four, which is 5.55%. The criterion of choosing the lowest value of OBC is based on the cost analysis of the asphalt. It means that smaller amount of bitumen required to produced the same quantity of mix will be much more economical. However, if the costs of the whole material are taken into consideration, there is a discrepancy in term of choosing the best mixture. The cost analysis will be discussed in the next part of this chapter.

4.5.3 Cost analysis

The cost analysis is made taking into consideration the cost of coarse aggregate, fine aggregate, and asphalt. The calculation is based on the calculation of pavement costs by the Asphalt Institute.

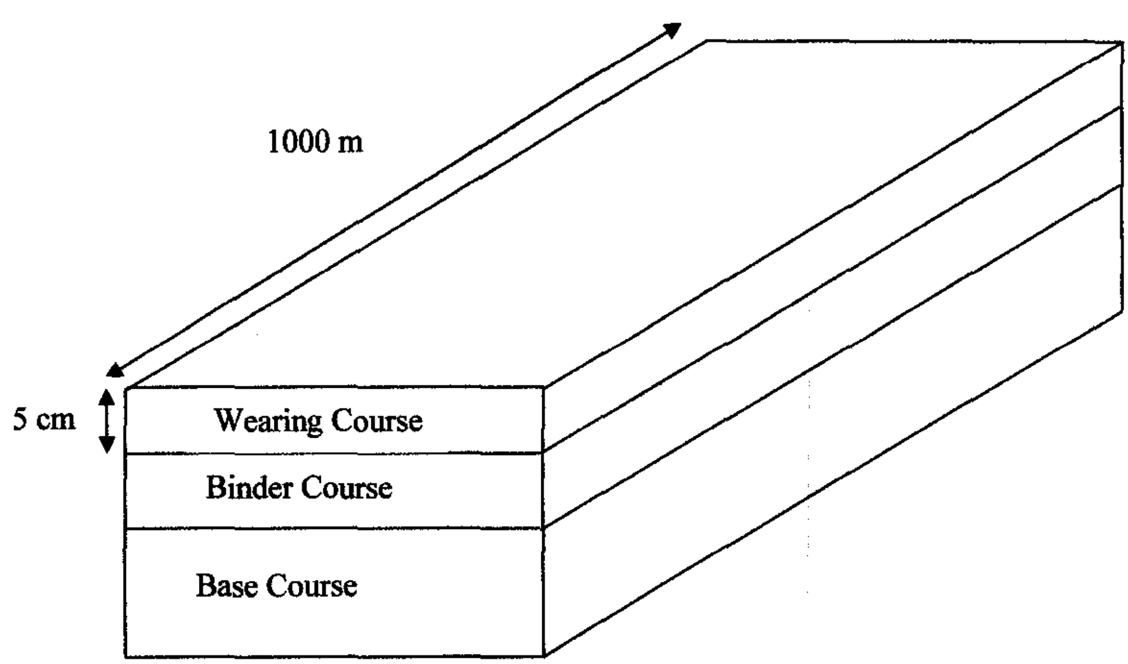

Figure 10: Cross Section of a Pavement

The calculation is only concentrated on the wearing course, with 5 cm (1.97 in) thickness and at a stretch of 1000m, as illustrated in Figure 10. The following information was obtained from the recent market price.

Asphalt, RM 826 per ton

Coarse aggregate (granite), RM180 per ton

Coarse aggregate (limestone), RM150 per ton

Fine aggregate, RM45 per ton

Multipliers are selected for each of the pay items and their corresponding pay units from the Table 1.1 in the guideline (Refer Appendix E).

i. Wearing Course (for mixture with well-graded granite) (Table 1.1, 2270 kg/m^3):

Coarse aggregate:	RM 180 per ton x 0.0496 x 1.97 in.	= RM 17.59 per sq yd
Fine aggregate:	RM 45 per ton x 0.0496 x 1.97 in.	= RM 4.40 per sq yd
Asphalt:	RM 826 per ton x 0.0029 x 1.97	= RM 4.72 per sq yd
Total		= RM 26.70 per sq yd

Converting to m^2 = RM 26.70 per sq yd x 0.83613 = RM 22.32 per m^2

ii. Wearing Course (for mixture with gap-graded granite) (Table 1.1, 2290 kg/m^3):

Coarse aggregate:	RM 180 per ton x 0.05 x 1.97 in.	= RM 17.73 per sq yd
Fine aggregate:	RM 45 per ton x 0.05 x 1.97 in.	= RM 4.43 per sq yd
Asphalt:	RM 826 per ton x 0.00365 x 1.97	= RM 5.94 per sq yd
Total		= RM 28.10 per sq yd

Converting to m^2 = RM 28.10 per sq yd x 0.83613 = RM 23.50 per m^2

iii. Wearing Course (for mixture with well-graded limestone) (Table 1.1, 2290 kg/m^3):

Coarse aggregate:	RM 150 per ton x 0.051 x 1.97 in.	= RM 15.07 per sq yd
Fine aggregate:	RM 45 per ton x 0.051 x 1.97 in.	= RM 4.52 per sq yd
Asphalt:	RM 826 per ton x 0.003019 x 1.97	= RM 4.91 per sq yd
Total		= RM 24.50 per sq yd

Converting to m^2 = RM 24.50 per sq yd x 0.83613 = RM 20.50 per m^2

iv. Wearing Course (for mixture with gap-graded limestone) (Table 1.1, 2220 kg/m^3):

Coarse aggregate: RM 150 per ton x 0.0484 x 1.97 in. = RM 14.30 per sq yd

Fine aggregate: RM 45 per ton x 0.0484 x 1.97 in. = RM 4.30 per sq yd

Asphalt: RM 826 per ton x 0.00364 x 1.97 = RM 5.92 per sq yd

Total = RM 24.35 per sq yd

Converting to m^2 = RM 24.53 per sq yd x 0.83613 = RM 20.51 per m^2

Table 21: Cost Summary of the Different Bituminous Mixture

Bituminous Mixture	Cost (RM per m^2)	Total cost for 1000m stretch (RM/ 1m width)
Granite (gap-graded)	23.50	23,500
Granite (well-graded)	22.32	22,320
Limestone (gap-graded)	20.51	20,510
Limestone (well-graded)	20.50	20,500

Based on the cost summary in Table 21, it is clearly shown that mixture of limestone with well gradation provides the lowest cost. If considering the whole material cost, the cost of bitumen alone does not have significant effect on the total cost. The most effecting factor is the cost of aggregate. In current market, the price of granite is higher than limestone. In addition, if considering the gradation of the same aggregate type, well- graded is surely contribute to lower cost as compared to gap-graded because well gradation required less bitumen content.

4.5.4 Summary of the Result

The combination of granite with well gradation seems to be the best combination as it incorporated stronger aggregate, which is granite. It is verified from the previous test on the aggregate (Aggregate impact value and LA abrasion value) that granite has higher strengths compared to limestone. However if considering in term of cost, limestone will be better as granite has higher market price compared to limestone.

Aggregate gradation also plays an important role as a good grading can produce a strong and economical bituminous mix. Well gradation refers to a sample that is approximately of equal amounts of various sizes of aggregate. The smaller size of aggregates can penetrate inside voids thus reduced the porosity of the mix. From the result, it is proved that well gradation is better than gap-gradation. In term of cost, well gradation also shows better performance as it requires much lesser bitumen than gap gradation.

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, 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.

i. From the result of particle density test, it is found that granite is denser than limestone. 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. Limestone shows higher water absorption value, and it is exceeding the JKR specification. Aggregate with higher water absorption value are porous and weak. So from the water absorption value obtained, it can be concluded that limestone has higher porosity and weaker than granite.
iii. From the results of abrasion value test, it is found that granite is more durable and can resist crushing under the roller better than limestone. Limestone with high L.A. abrasion loss values will tend to create dust during production and handling, which may produce environmental and mixture control problems.
iv. Aggregate impact value test indicates that granite strength is higher than limestone as lesser percentage of crushed aggregate recorded. It can be concluded that granite is more suitable as highway construction material as compared to limestone based on the strength criteria.
v. All the results for bitumen are complying with the requirements and thus conforming the first objective, which is to determine whether engineering properties of the materials are adequate to be used as construction aggregates in bituminous mixtures.

Marshall Method was used in order to determine the optimum binder content of various combinations of aggregate types and gradations. From the experimental results, it was proved that granite with well gradation produced the most optimum binder content.

i. Mixture of granite with well gradation has the highest stability value. While the mixture of gap-graded limestone has the lowest stability value, 1.2% lower than the acceptable value. It means that the mixture containing limestone with gap gradation has lower strength and it is not recommended to be used as the pavement material.
ii. The flow values for both mixtures of granite are low as compared to the allowable range. However, for well-graded granite mix, the value do not varies too much from the specified value. Low flow value may indicate a mix of insufficient asphalt content for durability, and also a mix that may experience premature cracking due to brittleness.
iii. Comparing the four mixtures in term of percentage of voids in the total mix, only mixture with well-graded granite shows the value within the allowable range. Other mixtures have very low voids, since those mixtures contain high percentage of finer aggregate that fills in the voids. Low VTM minimizes possibility that water gets into the mix, penetrate thin asphalt film and strip the asphalt cement off the aggregates.

Study concentrating on cost analysis of the materials, especially aggregates also had been done. The analysis is important to further study the aggregate in order to determine the most economical yet effective aggregate for the used in highway construction material.

i. From the analysis, limestone with well gradation shows the most economical price compared to others.
ii. In considering the most effective aggregate for industry, other properties should be taken into consideration, such as strength, durability and ability to withstand wear. If considering other properties, granite is proved to have greater performance compared to limestone.
iii. Well gradation is better than gap gradation as it provide stronger, less porous and also more economical bituminous mixture.

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APPENDICES

Appendix A	Typical value possible for road stone aggregates in relation to their geological classification.
Appendix B	Result of Specific Gravity Test for Filler (Printed from Ultrapycnometer 1000)
Appendix C	Result for Marshall test for granite and limestone with different aggregate gradation
Appendix D	Marshall Test Property Curves
Appendix E	Table 1.1: Asphalt concrete and other asphalt paving mixture (Asphalt Institute)
Appendix F	Project Gantt chart

APPENDIX A

TYPICAL VALUE POSSIBLE FOR ROAD STONE AGGREGATES IN RELATION TO THEIR GEOLOGICAL CLASSIFICATION (ROBERT, 1994)

	Rock types	Mechanical				Physical		Weathering		Stripping
	Test	ACV	AAV	AIV	PSV	RD	WA	S	FT	
Igneous	Basalt range	14 (15-39)	8 (3-15)	27 (17-33)	61 (37-74)	2.71 (2.6-3.4)	0.7 (0.2-1.8)	Low to high	Low to high	No
	Porphyry range	14 (9-29)	4 (2-9)	14 (9-23)	58 (45-73)	2.73 (2.6-2.9)	06 (0.4-41.1)	Medium	Low	No
Metamorphic	Granite range	20 (9-35)	5 (3-9)	19 (9-35)	55 (47-72)	2.69 (2.6-3)	0.4 (0.2-2.9)	Low	Low	Yes
	Quartzite range	16 (9-25)	3 (2-6)	21 (11-33)	60 (47-69)	2.62 (2.6-2.7)	0.7 (0.3-1.3)	Low	Low	Yes
Sedimentary	Gritstone range	17 (7-29)	7 (2.16)	19 (9-35)	74 (62-84)	2.69 (2.6-2.9)	0.6 (0.6-1.6)	Low to high	Medium	No
	Limestone range	24 (11-37)	14 (7-26)	23 (17-33)	45 (32-77)	2.66 (2.5-2.8)	1.0 (0.2-2.9)	Low to high	Low to high	No
Pits	Gravels range	20 (18-25)	7 (5-10)	15 (10-20	50 (45-58)	2.65 (2.6-2.9)	1.5 (0.9-2.0)	Low to high	Low to high	Yes
Artificial	Slag range	28 (15-39)	8 (3-15)	27 (17-33)	61 (37-74)	2.71 (2.6-3.2)	0.7 (0.2-2.6)	Low to high	Low to high	No

ACV = aggregate crushing value
AAV = aggregate abrasion value
AIV = aggregate impact value
F = freeze thaw
PSV = polished stone value
RD= relative density
S = soundness
WA = water absorption

APPENDIX B

RESULT OF SPECIFIC GRAVITY TEST FOR FILLER (PRINTED FROM ULTRAPYCNOMETER 1000)

QUANTACHROME CORPORATION
Ultrapycnometer 1000 Version 2.2
Analysis Report

Sample & User Parameters

Sample ID: OPC
Weight: 3.7756 grams
Analysis Temperature: 34.0 degC

Date: 04-29-08
Time: 16:56:08
User ID: 6241

Analysis Parameters

Cell Size: Small
V added - Small: 12.4554 cc
V cell: 20.9726 cc
Target Pressure: 19.0 psi
Equilibrium Time: Auto
Flow Purge: 1:00 min.
Maximum Runs: 6
Number of Runs Averaged: 3

Results

Deviation Requested: 0.005 %
Average Volume: 1.1363 cc
Average Density: 3.3227 g/cc
Coefficient of Variation: 0.3330 %

Deviation Achieved: +/- 0.1469
Std. Dev. : 0.0038 cc
Std. Dev. : 0.0111 g/cc

Tabular Data

RUN	VOLUME (cc)	DENSITY (g/cc)
1	1.1372	3.3201
2	1.1390	3.3148
3	1.1306	3.3395
4	1.1322	3.3348
5	1.1354	3.3252
6	1.1413	3.3081

APPENDIX C

RESULT FOR MARSHALL TEST FOR GRANITE AND LIMESTONE WITH DIFFERENT AGGREGATE GRADATION

FYP 2 MARSHALL MIX DESIGN & TEST (GRANITE)

Bitumen Grade: 80/100 Specific Gravity of Bitumen: 1.03 Specific Gravity of Granite: 2.56

Aggregate Gradation: Gap Graded Coarse Agg: 35 %, 420 g Fine Agg: 55 %, 660 g Filler: 10 %, 120 g

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

FYP 2 MARSHALL MIX DESIGN & TEST (LIMESTONE)

Bitumen Grade: 80/100 Specific Gravity of Bitumen: 1.03 Specific Gravity of Limestone: 2.50

Aggregate Gradation: Gap Graded Coarse Agg: 35 %, 420 g Fine Agg: 55 %, 660 g Filler: 10 %, 120 g

Binder Content (%)	Sample No.	Height (mm)	Mass of Specimen		Volume (cm³)	Specific Gravity		Air Voids (%)		Flow (mm)	Stability (kN)		
			In Air (g)	In Water (g)		Bulk	Theory	Total Mix	VMA		Measured	C.F.	Corrected
6.0	1	69.48	1228.0	669.5	558.5	2.18	2.30	5.22	21.49	2.10	4.73	0.89	4.21
	2	68.94	1246.5	680.0	566.5					2.14	4.99	0.89	4.44
6.5	1	68.61	1247.5	681.0	566.5	2.19	2.29	4.37	21.55	2.23	4.97	0.89	4.42
	2	68.91	1269.0	699.5	569.5					2.25	4.86	0.93	4.52
7.0	1	68.69	1276.0	702.0	574.0	2.22	2.27	2.33	20.90	2.26	5.13	0.89	4.57
	2	68.99	1270.0	699.0	571.0					2.30	5.95	0.89	5.30
7.5	1	68.69	1241.0	679.5	561.5	2.21	2.26	2.21	21.68	2.63	5.52	0.89	4.91
	2	68.93	1263.0	694.0	569.0					2.45	5.36	0.89	4.77
8.0	1	68.34	1294.5	724.0	570.5	2.20	2.24	1.79	22.45	2.72	5.02	0.93	4.67
	2	68.01	1250.0	716.5	533.5					3.01	3.51	0.89	3.12

FYP 2 MARSHALL MIX DESIGN & TEST (GRANITE)

Bitumen Grade: 80/100 Specific Gravity of Bitumen: 1.03 Specific Gravity of Granite: 2.56

Aggregate Gradation: Well Graded 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	69.64	1210.5	654.5	556.0	2.19	2.40	8.75	20.17	0.93	3.95	0.89	3.52
	2	71.03	1215.5	655.0	560.5					1.09	4.23	0.86	3.64
5.0%	1	70.15	1239.5	678.0	561.5	2.24	2.38	6.30	18.78	1.15	5.15	0.86	4.43
	2	69.07	1221.0	669.0	552.0					1.08	5.43	0.89	4.83
5.5%	1	71.18	1248.0	684.0	564.0	2.27	2.37	4.22	18.12	1.72	6.51	0.86	5.60
	2	70.12	1233.0	686.0	547.0					1.90	7.24	0.89	6.44
6.0%	1	71.10	1268.0	694.0	574.0	2.26	2.35	3.83	18.92	1.95	6.03	0.83	5.00
	2	69.07	1250.5	687.0	563.5					2.01	6.22	0.86	5.35
6.5%	1	70.81	1268.5	699.5	569.0	2.24	2.33	3.86	20.06	2.05	5.21	0.86	4.48
	2	70.36	1253.0	680.0	573.0					2.18	5.40	0.86	4.64

FYP 2 MARSHALL MIX DESIGN & TEST (LIMESTONE)

Bitumen Grade: 80/100 Specific Gravity of Bitumen: 1.03 Specific Gravity of Limestone: 2.50

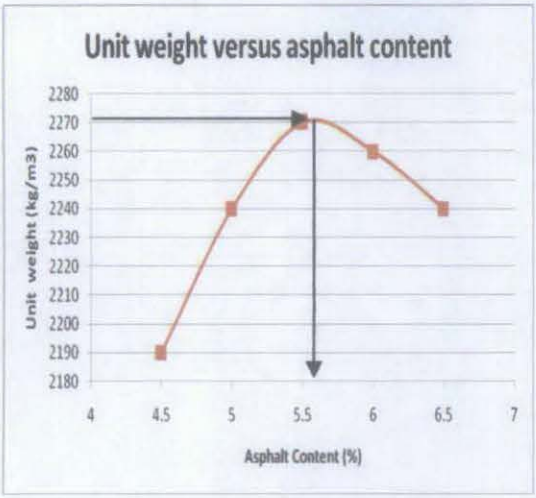
Aggregate Gradation: Well Graded Coarse Agg: 42 %, 504 g Fine Agg: 50 %, 600 g Filler: 8 %, 96 g

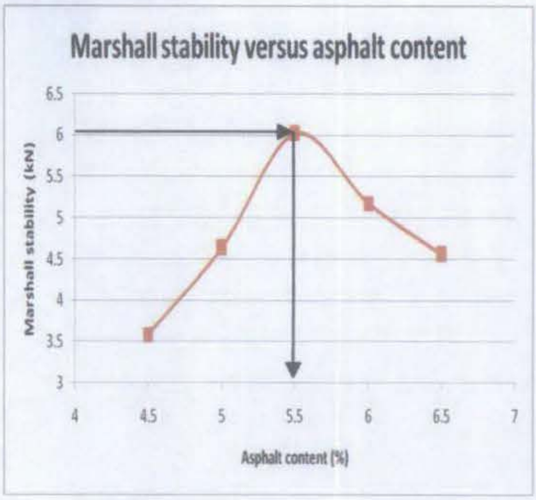
Binder Content (%)	Sample No.	Height (mm)	Mass of Specimen		Volume (cm^3)	Specific Gravity		Air Voids (%)		Flow (mm)	Stability (kN)		
			In Air (g)	In Water (g)		Bulk	Theory	Total Mix	VMA		Measured	C.F.	Corrected
4.5%	1	68.04	1197.0	664.5	532.5	2.22	2.35	5.53	18.14	1.67	4.01	0.96	3.85
	2	70.39	1242.5	676.0	566.5					1.74	3.78	0.86	3.25
5.0%	1	69.61	1247.5	697.5	557.0	2.23	2.33	4.29	18.20	1.81	5.06	0.89	4.50
	2	70.48	1254.5	687.0	567.5					2.08	5.23	0.86	4.50
5.5%	1	67.71	1251.5	705.0	546.5	2.27	2.32	2.16	17.18	2.14	6.01	0.89	5.35
	2	68.49	1237.0	692.0	545.0					2.02	6.42	0.93	5.97
6.0%	1	69.93	1279.0	719.5	559.5	2.29	2.30	0.56	16.89	2.16	5.16	0.86	4.44
	2	69.20	1270.0	714.0	556.0					2.08	5.32	0.89	4.73
6.5%	1	68.34	1257.5	712.5	545.0	2.27	2.29	0.87	18.05	2.07	5.02	0.93	4.67
	2	68.01	1295.5	710.5	585.0					2.23	4.95	0.83	4.11

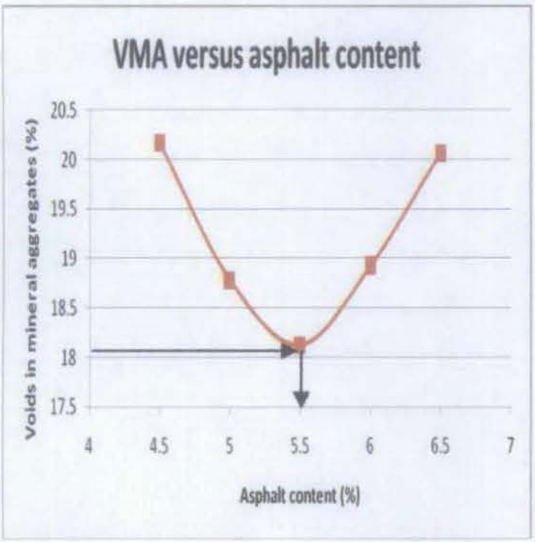
APPENDIX D

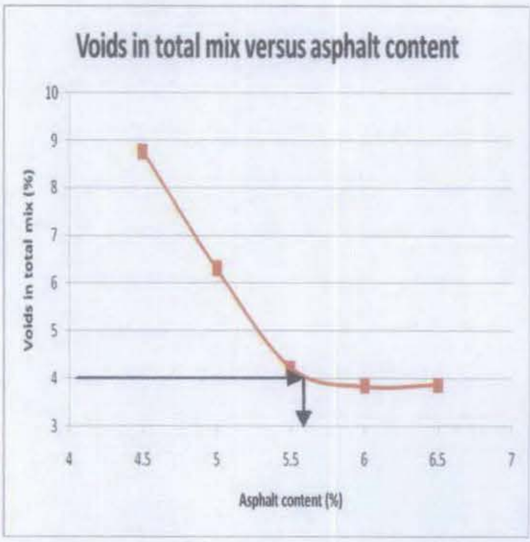
MARSHALL TEST PROPERTY CURVES

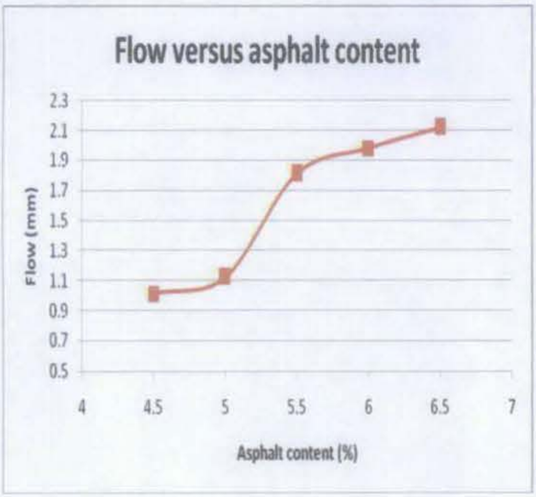
i. Bituminous mixture of Granite with Well gradation









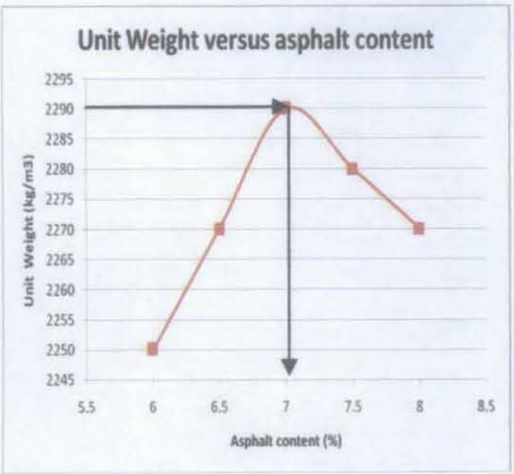


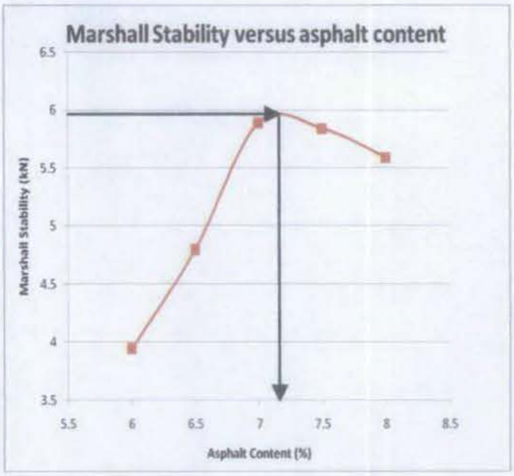
1. Maximum unit weight = 5.6%
2. Maximum stability = 5.5%
3. Minimum VMA = 5.5%
4. Air voids in total mix at 4% = 5.6%

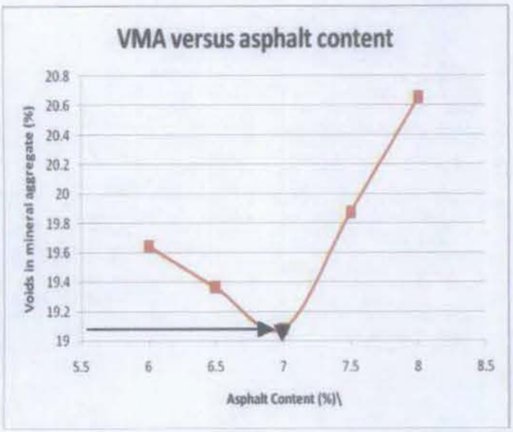
The optimum asphalt content is determined as the average:

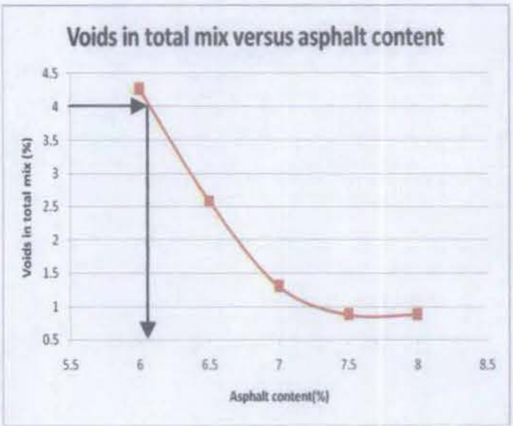
$$\frac{5.6+5.5+5.5+5.6}{4} = 5.55\%$$

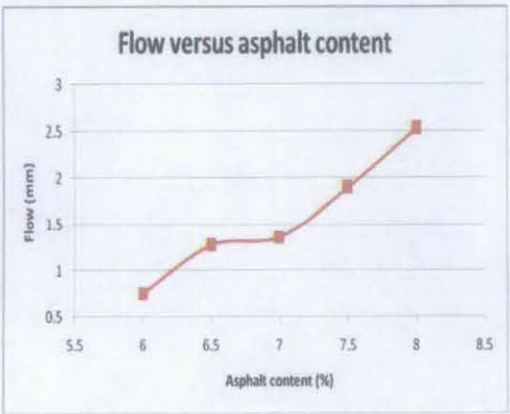
ii. Bituminous mixture of Granite with Gap gradation









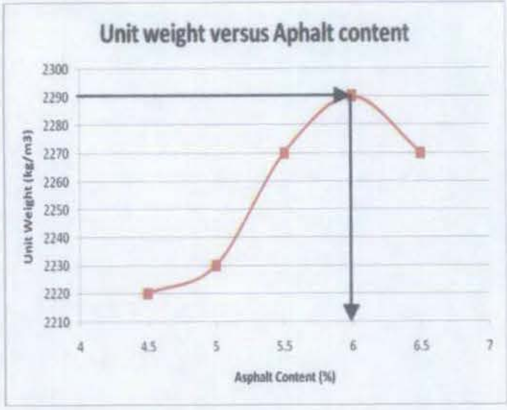


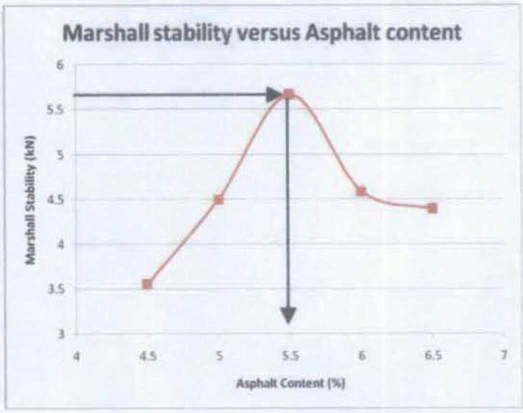
1. Maximum unit weight = 7.0%
2. Maximum stability = 7.1%
3. Minimum VMA = 7.0%
4. Air voids in total mix at 4% = 6.1%

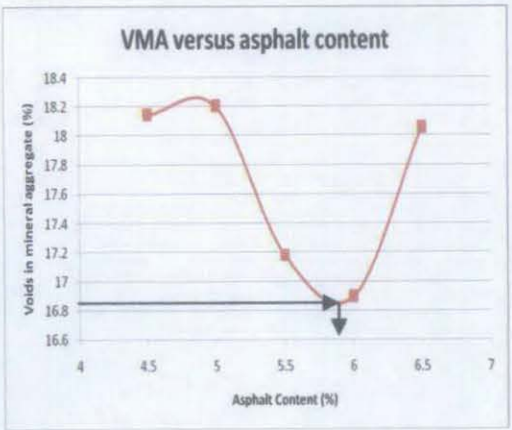
The optimum asphalt content is determined as the average:

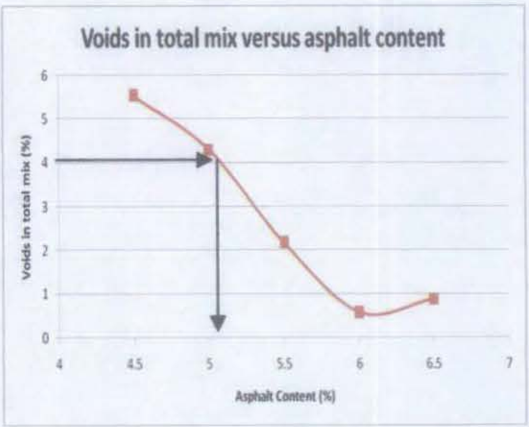
$$\frac{7.0+7.1+7.0+6.1}{4} = 6.8\%$$

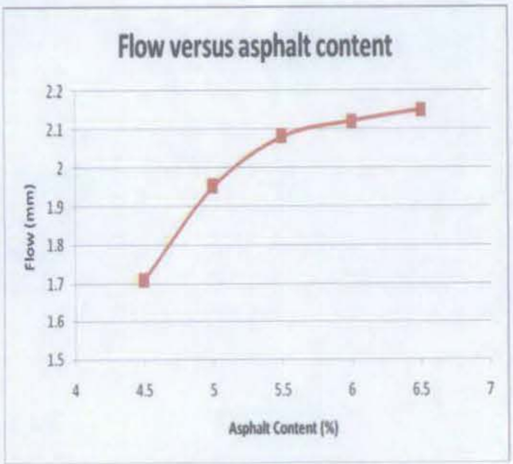
iii. Bituminous mixture of Limestone with Well gradation









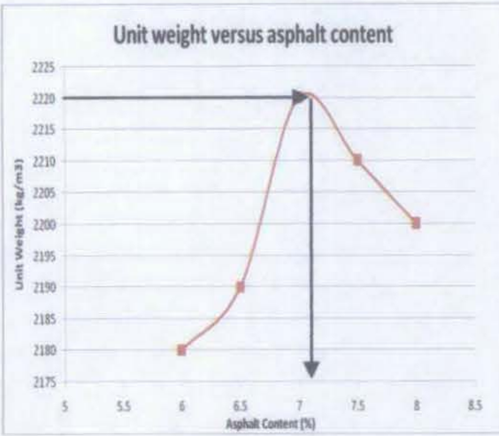


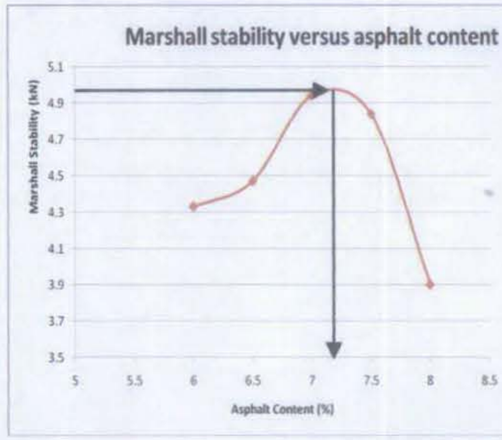
1. Maximum unit weight = 6.0%
2. Maximum stability = 5.5%
3. Minimum VMA = 5.9%
4. Air voids in total mix at 4% = 5.1%

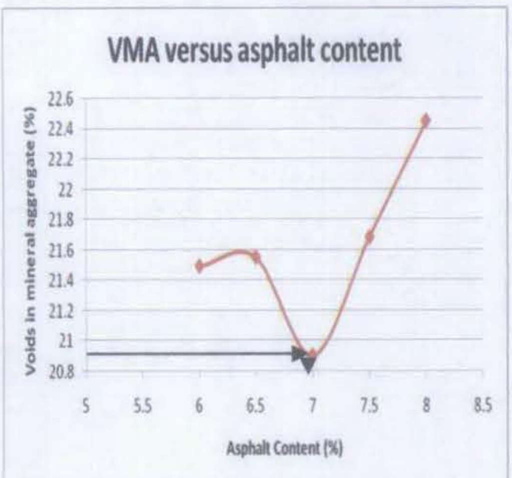
The optimum asphalt content is determined as the average:

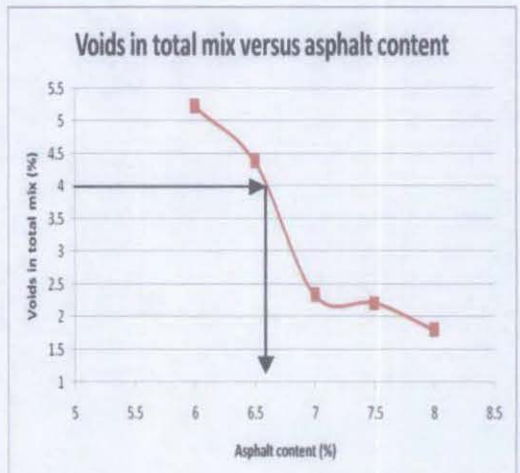
$$\frac{6.0+5.5+5.9+5.1}{4} = 5.63\%$$

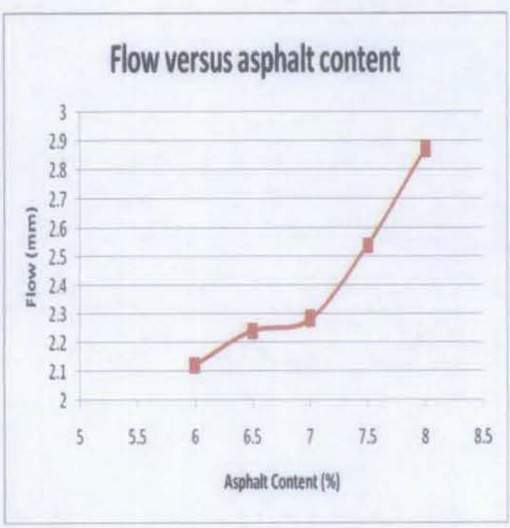
iv. Bituminous mixture of Limestone with Gap gradation











1. Maximum unit weight = 7.1%
2. Maximum stability = 7.2%
3. Minimum VMA = 7.0%
4. Air voids in total mix at 4% = 6.6%

The optimum asphalt content is determined as the average:

$$\frac{7.1+7.2+7.0+6.6}{4} = 7.0\%$$

APPENDIX E

TABLE 1.1: ASPHALT CONCRETE AND OTHER ASPHALT PAVING MIXTURE (ASPHALT INSTITUTE)

Table I-1
Asphalt Concrete and Other Asphalt Paving Mixes

The following assumptions are made for determining the multipliers for asphalt concrete and other asphalt paving mixes.

asphalt content, 5.5 percent by weight of mix
asphalt cement, 235 gal/ton @ 60° F
cutback asphalt, 245 gal/ton @ 60° F
emulsified asphalt, 241 gal/ton @ 60° F

Multipliers (M) for Converting Unit Costs to Costs Per Sq Yd-In.

Pay Item		Pay Unit	Compacted density, lb/cu ft* 130	135	140	145	150
Asphalt concrete	(1)	per ton	0.0488	0.0506	0.0525	0.0544	0.0563
Asphalt	(2)	per ton	0.0027	0.0028	0.0029	0.0030	0.0031
Asphalt cement	(4)	per gal	0.6301	0.6543	0.6786	0.7028	0.7270
Cutback asphalt	(4)	per gal	0.6569	0.6822	0.7074	0.7327	0.7580
Emulsified asphalt	(4)	per gal	0.6462	0.6710	0.6959	0.7207	0.7456
Aggregate	(3)	per ton	0.0461	0.0478	0.0496	0.0514	0.0532
Aggregate	(5)	per cu yd	0.0278	0.0278	0.0278	0.0278	0.0278

General Formulae:

(1) $M = 0.75\ D/2000$

(2) $M = 0.75\ P_a D/2000\ (100)$

(3) $M = 0.75\ P_s D/2000\ (100)$

(4) $M = 0.75\ P_a DG/2000\ (100)$

(5) $M = 1/36$

$0.75 = \frac{27 \text{ cu ft}}{\text{cu yd}} \times \frac{\text{yd}}{36 \text{ in}}$

D = density, lb per cu ft

P_a = asphalt content, percent by weight of mix

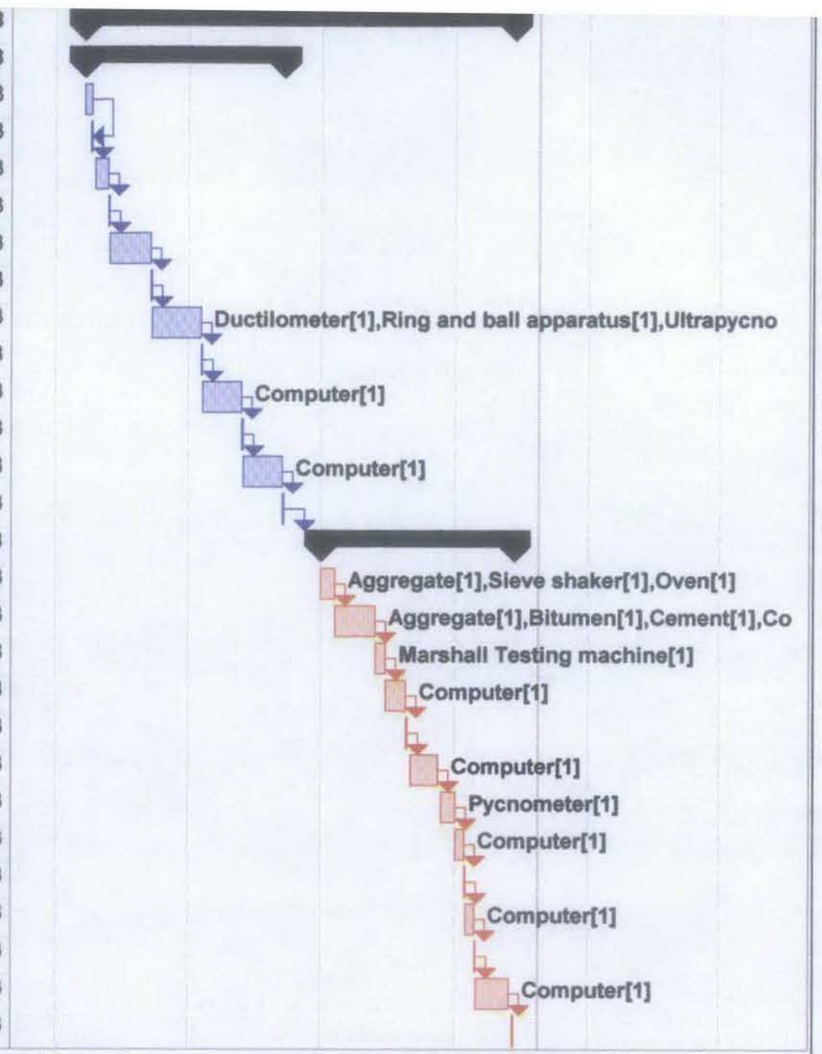
P_s = aggregate content ($100-P_a$), percent by weight of mix

G = gallons per ton

*Suggested densities for different asphalt mixes are shown below:

dense-graded asphalt concrete,	145 lb per cu ft
coarse-graded asphalt hot mixes,	140 lb per cu ft
fine-graded asphalt hot mixes,	140 lb per cu ft
stone sheet asphalt hot mixes,	140 lb per cu ft
open-graded asphalt hot mixes,	135 lb per cu ft
dense-graded, mixed-in-place,	135 lb per cu ft
coarse-graded, mixed-in-place,	130 lb per cu ft

1	**FINAL YEAR PROJECT**	**211 days**	**Mon 1/21/08**	**Mon 11/10/08**
2	**Final Year Project 1**	**99 days**	**Mon 1/21/08**	**Thu 6/5/08**
3	Initiation of project title	5 days	Mon 1/21/08	Fri 1/25/08
4	Submission of project title	1 day	Fri 1/25/08	Fri 1/25/08
5	Preliminary literature research	7 days	Mon 1/28/08	Tue 2/5/08
6	Submission of project proposal	1 day	Wed 2/6/08	Wed 2/6/08
7	Supplementary literature research	20 days	Thu 2/7/08	Wed 3/5/08
8	Submission of progress report 1	1 day	Thu 3/6/08	Thu 3/6/08
9	Preliminary data colllection - material properties	24 days	Fri 3/7/08	Wed 4/9/08
10	Submission of progress report 2	1 day	Thu 4/10/08	Thu 4/10/08
11	Supplementary data collection - material propert	19 days	Fri 4/11/08	Wed 5/7/08
12	Submission of FYP1 final report	1 day	Thu 5/8/08	Thu 5/8/08
13	Preparation of presentation slide for FYP1	19 days	Fri 5/9/08	Wed 6/4/08
14	FYP1 oral presentation	1 day	Thu 6/5/08	Thu 6/5/08
15	**Final Year Project 2**	**95 days**	**Tue 7/1/08**	**Mon 11/10/08**
16	Preparation of materials	8 days	Tue 7/1/08	Thu 7/10/08
17	Preparation of bituminous mixture samples	20 days	Fri 7/11/08	Thu 8/7/08
18	Conducting Marshall Test on the samples	5 days	Fri 8/8/08	Thu 8/14/08
19	Analysis of the data	10 days	Fri 8/15/08	Thu 8/28/08
20	Submission of progress report 3	1 day	Fri 8/29/08	Fri 8/29/08
21	Additional literature research	15 days	Mon 9/1/08	Fri 9/19/08
22	Supplementary data collection - material propert	8 days	Mon 9/22/08	Wed 10/1/08
23	Preparation of poster	4 days	Thu 10/2/08	Tue 10/7/08
24	Poster presentation	1 day	Wed 10/8/08	Wed 10/8/08
25	Preparation of dissertation report	4 days	Thu 10/9/08	Tue 10/14/08
26	Submission of dissertation report	1 day	Wed 10/15/08	Wed 10/15/08
27	Preparation of presentation slide for FYP2	17 days	Thu 10/16/08	Fri 11/7/08
28	FYP2 oral presentation	1 day	Mon 11/10/08	Mon 11/10/08



Project: Assignment 3
Date: Thu 11/27/08