TENSILE AND FATIGUE PROPERTIES OF BITUMINOUS MIXTURES BETWEEN LIMESTONE AND RECYCLE CONCRETE AGGREGATES

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By

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FINAL PROJECT REPORT

Submitted to the Civil Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Civil Engineering)

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved:

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UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

June 2010

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.

(Faizal Azfar bin Zulkefli)

ABSTRACT

The purpose of this study is to determine the tensile and fatigue properties of bituminous mixture using limestone and recycle concrete aggregates, which were obtained through planned laboratory processing. The objective of this work is to understand the behaviour of bituminous mixtures, as well as investigating the numerical relationship between the properties of aggregates on the behaviour and performance of bituminous mixtures. The performance of a bituminous mixture is greatly influenced by the properties of the aggregate used. Many studies have been conducted on this subject matter globally, which is not specific to the tensile and fatigue properties of the bituminous mixture. Usual methods to determine the characteristic of the mixture use involved several tests such as the Indirect Tensile Stiffness Module Test and Beam Fatigue Test. This project also attempts to address the most suitable aggregate type to be used in bituminous mixture. Different aggregate have their own strength, physical and chemical properties that will affect the strength and stiffness of the bitumen mixtures.

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CHAPTER 1
INTRODUCTION

1.1 Background of study

The term bituminous materials are generally used to denote substances in which bitumen is present or from which it can be derived [Goetz and Wood, 1960]. A bituminous mixture is a combination of bituminous materials (as binders), properly graded aggregates and additives. For civil engineering applications, bituminous mixtures include primarily asphalts and tars. Since tar is rarely used in bituminous mixtures in recent years and asphalt is the predominant binder material used, the term "asphalt mixture" is now more commonly used to denote a combination of asphalt materials, aggregates and additives.

This project is carried out to do research about the different of limestone and recycle concrete aggregates on the tensile and fatigue properties of bituminous mixture. This project focuses more on the experiment and analysis of the aggregate that commonly used in the road constructions. Aggregate makes up 90-95 percent by weight and 75-85 percent by volume of most bituminous mixtures. Aggregate provides most of the load-bearing capacity of the bituminous mixture. Thus, the performance of a bituminous mixture is greatly influenced by the properties of the aggregate used.

One of the most important characteristics of an aggregate, which affect the performance of an asphalt mixture, is its gradation. The properties of an asphalt mixture could be changed substantially when the aggregate gradation is altered.

Many studies indicated that asphalt binder chemistry, aggregate mineralogy, aggregate surface texture, and the interaction between asphalt and aggregate significantly affect moisture susceptibility. The large numbers of different aggregate mineralogies and the different types of asphalt binders used across the world, coupled with varied environmental conditions, traffic, and construction practices, have should be fairly well graded to made testing to predict accurately hot-mix asphalt moisture susceptibility a difficult task.

Fatigue failure of the Hot Mix Asphalt (HMA) surface happens because of a repeated traffic loading. In thin pavements, cracking initiates at the bottom of the HMA layer where the tensile stress is the highest then propagates to the surface as one or more longitudinal cracks. This is commonly referred to as "bottom-up" or "classical" fatigue cracking. In thick pavements, the cracks most likely initiate from the top in areas of high localized tensile stresses resulting from tire-pavement interaction and asphalt binder aging. After repeated loading, the longitudinal cracks connect forming many-sided sharp-angled pieces that develop into a pattern resembling the back of an alligator or crocodile. Tensile properties indicate how the material will react to forces being applied in tension. Tensile testing is performed by elongating a specimen and measuring the load carried by the specimen. From the knowledge of the specimen dimensions, the load and deflection data can be translated into a stress-strain curve. A variety of tensile properties can be extracted from the stress-strain curve. Tensile tests are used to determine the modulus of elasticity, elastic limit, elongation, proportional limit, reduction in area, tensile strength, yield point, yield strength and other tensile properties.

This project concentrates more into experimental and analysis works. Different types of aggregates will incorporate with different type of bituminous mixtures. The purposed of mixture with different types of aggregates is to have a safe and economical road pavement and better quality services. The bituminous mix design aims to determine the proportion of bitumen, filler, fine aggregates, and coarse aggregates to produce a mix that workable, durable and economical.

1.2 Problem statement

Several traffic and environmental factors affect the deterioration of roads. A substantial part of the damage on flexible pavements is caused by cracking of the asphalt concrete layer. Different types of cracking occur, such as fatigue cracking and low temperature cracking. Fatigue (alligator) cracking is considered to be one of the most significant distress modes in pavement, associated mainly with repeated traffic load. Fatigue of pavements is a very complex phenomena caused by cyclic loading of traffic passing over the pavement. Fatigue cracking leads to poor pavement performance, which in turn increases maintenance as well as road user cost.

Long and expensive tests are required to assess the mechanical characteristics of bituminous mixtures for the purpose of pavement design and performance prediction. When the mechanical characteristics are called for, fatigue performance is required. Extensive efforts have been made to predict the fatigue life, or the number of cycles causing failure based on the mechanical behavior in stages earlier than the fracture of hot-mix asphalt (HMA).

The three constituents: asphalt binder, aggregates, and voids are usually not uniformly distributed within a mixture, resulting in the spatial gradients of the local volume fractions of these constituents. Because of inhomogeneous distribution, the effective properties such as stiffness modulus also vary with spatial locations, resulting in inhomogeneous induced stress concentration and/or strain localization.

Therefore, it is necessary to acquire more insight into the tensile and fatigue properties of bituminous mixtures in order to obtain a better understanding of the cracking mechanism of asphalt pavements and to have a practical and reliable system to determine the resistance of mixture to crack development and propagation. With this study of effects of different aggregates types on the tensile and fatigue properties of bituminous mixture, we can identify the effect of the road strength by using different aggregates type in different type of bitumen grades.

1.3 Objectives

The main purpose of this paper was to achieve the following objective:

- Study the effect of aggregate types on the tensile and fatigue properties of bituminous mixture.

1.4 Scope of study

There are there elements that are important in this project which are the tensile and fatigue behaviour of bituminous mixture, types of bituminous mixture and the types of aggregates use in the mixing. Therefore, there a two type of bituminous mixture will be prepared which is Limestone with Asphaltic Concrete with 80/100 pen of bitumen and Recycle Concrete Aggregates with Asphaltic Concrete with 80/100 pen of bitumen.

The effect of different aggregates can be determine by looking at the tensile and fatigue properties of the mixtures. A laboratory test will be conduct in order to identify the tensile and fatigue parameters. The tests that will be conduct are Indirect Tensile Stiffness Modulus and Beam Fatigue Test.

CHAPTER 2
LITERATURE REVIEW

Asphalt pavement failure is a complicated phenomena. It is a result of cumulative damage in different pavement layers. The influence of moisture on hot-mix asphalt (HMA) stripping is difficult to characterize due to the presence of many factors affecting this damage. One of the major problems affecting the performance of hot-mix asphalt is stripping.

Many studies indicated that asphalt binder chemistry, aggregate mineralogy, aggregate surface texture, and the interaction between asphalt and aggregate significantly affect moisture susceptibility. The large numbers of different aggregate mineralogies and the different types of asphalt binders used across the world, coupled with varied environmental conditions, traffic, and construction practices, have made testing to predict accurately hot-mix asphalt moisture susceptibility a difficult task. Aggregate mineral and chemical composition, exposure history (e.g., freshly crushed versus days of exposure to environmental weathering after crushing) have significant effects on stripping. Hydrophilic (water loving) aggregates should be avoided unless an antistripping additive is used.

Angular aggregates, sometimes, increase the stripping potential. This can be explained by the fact that angular aggregates increase the potential of film rupture at the aggregate sharp edges. Using high-viscosity asphalt produces hot-mix asphalt with higher resistance to stripping. However, low viscosity asphalt is desirable during mixing operations, since low viscosity asphalt has more spreading ability which produces better aggregate coating during mixing.

In another study, Abo-Qudais studied the effect of using different evaluation techniques on the predicted stripping of 24 different HMA combinations prepared using different mix parameters. Similar mix parameters as those in a previous study were used. The stripping evaluation techniques include percent reduction in both indirect tensile strength and Marshall stability, percent increase in creep due to stripping, in addition to stripping visual evaluation using the Texas boiling test. The findings of this study indicated that the estimated stripping is affected significantly by the method of evaluation. The reduction in indirect tensile strength and Marshall stability were found to be less sensitive to stripping than the percent increase in creep. Also, percent increase in creep was the only one among the methods used that was able to determine the effect of used asphalt and aggregate gradation on the stripping of HMA.

In the United States, experiences with use of open-graded mixes indicated that ravelling was the major cause of pavement failure in some regions, while a vast majority of states had a good experience with the use of polymer modified asphalt binders. Nielsen et al observe that in Japan, porous asphalt surfaces on highways and in urban areas cover more than 50 millionm2. The structural durability of these pavements was found to be same as that of dense graded asphalt mixes, while climatic conditions too were found to have a significant influence. High viscosity styrene–butadiene–styrene (SBS) modified binders were used in these cold regions to overcome distresses due rutting and raveling.

Fatigue cracking at pavement usually starts as microcracks that later develop to form macrocracks that propagate due to tensile or shear stress, or combinations of both, causing disintegration and final failure of material because of unstable crack growth. Pavement serviceability is reduced as these cracks propagate and disintegrate occurs. Mixtures resistant to crack development and propagation affect the cracking performance of asphalt pavements. Therefore, it is necessary to acquire more insight into the crack behavior of asphalt concrete mixtures in order to obtain a better understanding of the cracking mechanism of asphalt pavements and to have a practical and reliable system to determine the resistance of mixture to crack development and propagation. Different fatigue failure criteria have been used by different researchers. However, none of the criteria was correlated to fracture of HMA. For example; Kim et al. used 0.25 cm horizontal deformation as its failure criterion. Another study by Sousa et al considered the failure criterion as the reduction of stiffness modulus of half of the initial stiffness modulus. Kim et al. reported that different failure criteria were used by different researchers. One of these criteria considered the failure occurs when the permanent horizontal deformation reaches between 0.71 and 0.91 cm. Other criteria based on changes in dissipated energy including dissipated energy ratio or damage accumulation ratio were used. The change in the phase angle during fatigue testing has also been used as fatigue failure criterion.

Moisture damage is an extremely complicated mode of asphalt mixture distress that leads to the loss of stiffness and structural strength of the bound pavement layers of a road and eventually the costly failure of the road structure. Essentially the damage is caused by a loss of adhesion between aggregate and bitumen and/or a loss of cohesion strength in the bitumen and/or bitumen–filler mastic due to the presence of moisture in the asphalt mixture. Various test methods have been developed in an attempt to identify the susceptibility of asphalt mixtures to moisture damage and can generally be divided into those conducted on loose coated aggregate and those conducted on compacted asphalt mixtures. Tests on compacted mixtures generally use samples either prepared in the laboratory or cored from existing pavements. Typically, the samples are conditioned in water to simulate in-service conditions and assessment of moisture damage is made by dividing the conditioned stiffness modulus or strength by the unconditioned stiffness modulus or strength. Tests of this nature include the accelerated water conditioning and freeze–thaw AASHTO T283 procedure. In addition, immersion wheel tracking tests, such as the Hamburg wheel tracking device, can be used to assess the moisture damage of asphalt mixtures. However, none of these tests has been found to accurately predict the magnitude of moisture damage (strength and/or stiffness reduction) of different asphalt mixtures in the field. Researchers at the Nottingham Transportation Engineering Centre (NTEC) have therefore recently developed a combined ageing/moisture damage laboratory test that has been shown to correctly predict the performance of asphalt mixtures in the field and replicate the magnitude of this moisture damage distress. The test, known as the Saturation Ageing Tensile Stiffness (SATS) test, consists of initial saturation under vacuum prior to placing compacted asphalt core samples in a high temperature and pressure environment in the presence of moisture for an extended period of time. The stiffness modulus measured after the test divided by the stiffness modulus measured before the test (retained stiffness modulus), and the specimen saturation after the test (retained saturation), are used as an indication of the sensitivity of the compacted mixture to the combined effects of ageing and moisture.

In another study, Brown and Bassett have evaluated five hot-mix asphalt mixes with different maximum aggregate sizes of crushed limestone used in preparing the specimens. The asphalt content of all mixes was selected to provide air void content of 4%. Specimens were evaluated using the Marshall, indirect tensile strength, creep, and resilient modulus tests. The creep test results indicated that the permanent strain of 4 in. specimens increased with an increase in the maximum size of aggregate.

CHAPTER 3
METHODOLOGY

The main approach of the project is to experiment the effect of the aggregate types on the tensile and fatigue properties of the bituminous mixtures. Few experimental guidelines that can be apply in the project such as:

- Indirect Tensile Stiffness Modulus (ITSM)
- Beam Fatigue Test (BFT)

The author need to incorporate the bituminous mixture with different bitumen grades which has been different type of aggregates which are Limestone, Granite and Recycle Concrete. In this experiment, the author will concentrate in one type of mixture which is Asphaltic Concrete (AC) incorporating with bitumen grade 80/100 penetration in well graded. In order to determine the relative proportions of different grain sizes, Sieve Analysis was being done. Specific Gravity and Water Absorption Test are also being done to determine the specific gravity for the aggregates and bitumen. For achieving the higher bitumen content, the author has done the Marshall Test.

3.1 Sieve Analysis

. The test was done determine determines the relative proportions of different grain sizes as they are distributed among certain size ranges. The grain size analysis is widely used in classification of soils. The data obtained from grain size distribution curves is used in the design of filters for earth dams and to determine suitability of soil for road construction, air field etc. Information obtained from grain size analysis can be used to predict soil water movement although permeability tests are more generally used. The apparatus for the experiment are:

- Stack of Sieves including pan and cover
- Rifle Box
- Mechanical sieve shaker
- Oven

Figure 1: Sieves used for gradation test.

Figure 2: A mechanical shaker used for sieve analysis.

<u>Procedure.</u>

1. Take a representative oven dried sample of soil that weighs about 500 g. (this is normally used for soil samples the greatest particle size of which is 4.75 mm)
2. If soil particles are lumped or conglomerated crush the lumped and not the particles using the pestle and mortar.
3. Determine the mass of sample accurately. Wt (g)
4. Prepare a stack of sieves. Sieves having larger opening sizes (i.e lower numbers) are placed above the ones having smaller opening sizes (i.e higher numbers). The very last sieve is #200 and a pan is placed under it to collect the portion of soil passing

#200 sieve. Here is a full set of sieves. (#s 4 and 200 should always be included).

Sieve Number	Opening Size (mm)
4	4.750
6	3.350
8	2.360
12	1.680
16	1.180
20	0.850
30	0.600
40	0.425
50	0.300
60	0.250
80	0.180
100	0.150
140	0.106
200	0.075
270	0.053

5. Make sure sieves are clean, if many soil particles are stuck in the openings try to poke them out using brush.
6. Weigh all sieves and the pan separately.
7. Pour the soil from step 3 into the stack of sieves from the top and place the cover, put the stack in the sieve shaker and fix the clamps, adjust the time on 10 to 15 minutes and get the shaker going.
8. Stop the sieve shaker and measure the mass of each sieve + retained soil.

The results are presented in a graph of percent passing versus the sieve size. On the graph the sieve size scale is logarithmic. To find the percent of aggregate passing through each sieve, first find the percent retained in each sieve. To do so, the following equation is used,

$$\%Retained = \frac{W_{Sieve}}{W_{Total}} \times 100\%$$

Where WSieve is the weight of aggregate in the sieve and WTotal is the total weight of the aggregate. The next step is to find the cumulative percent of aggregate retained in each sieve. To do so, add up the total amount of aggregate that is retained in each sieve and the amount in the previous sieves. The cumulative percent passing of the aggregate is found by subtracting the percent retained from 100%.

$$\%Cumulative\ Passing = 100\% - \%Cumulative\ Retained$$

The values are then plotted on a graph with cumulative percent passing on the y axis and logarithmic sieve size on the x axis.

3.2 Specific Gravity and Water Absorption Test

Specific gravity and water absorption test was carried out according to the ASTM Designation: C 127 -88.Aggregate usually contains pores, which are permeable and impermeable. Aggregates that having low specific gravity values are generally weaker than those having higher values. Aggregates with higher water absorption value are porous and thus weak.

A sample of 1kg of aggregate was taken first as a sample. The sample was dried and immersed in water for 24 hours. It was then removes from the water and surface dried. The saturated surface dried sample was weighed.

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)

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

Apparent particle gravity = D / D – (B – C)

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

3.3 Marshall Test

The purpose of Marshall Test is to obtain the Optimum Bitumen Contain of Asphalt Concrete Mixtures. There are two procedures in it. First is the preparation of the Asphalt Specimens and second is testing the Asphalt specimens. The apparatus for the experiment are :

- Gyratory testing machine
- Mechanical mixer
- Thermometer
- Water bath
- Electronic balance
- Buoyancy balance
- Marshall testing machine
- Oven

Figure 3 :Marshall Testing Machine

Procedure for preparation of the Asphalt Specimens.

1. All material are batched and kept in an oven at 150 °C. The mixer is also heated to the same level of temperature, therefore great care should be exercised when handling the hot material and equipment
2. The batched granular material (plus filler) should be place in the mixer and mixed dry for about 1 minute, then the appropriate amount of bitumen should be added to the aggregate. Mixing should continue until all particles are coated with bitumen.
3. The material should also be compacted in 100mm diameter steel moulds (which are also kept at 150°C - 160°C). After filling the mould with the appropriate amount of material, the operator should make sure that it is evenly distributed in the mould. This is done by tamping the material (using steel rod) 15 times around the edges and 5 times in the centre. At this stage, the sample is ready for compaction using the Gyratory Testing Machine which is set to the following standard conditions :

Axial load	=	0.7 MPa
Angle of gyration	=	1°
No. of revolutions	=	30

4. When the specimens have cooled down to room temperature, they are extruded from the modulus. The weight of each specimen in air and water and its height should be taken (for density calculations).
5. Three specimens are to be prepared for each bitumen content.

Procedure for testing the Asphalt specimens.

1. Heat the specimen in a water bath to a temperature of 60°C for 30 minutes.
2. Place the specimen in the Marshall testing rig. The breaking head of Marshall testing apparatus is also conditioned to 60°C.
3. Load the specimen radially at a constant rate of strain of 50.8mm/min.
4. Determine the stability of each specimen as the maximum load that the specimen could withstand.
5. Correct the stability value obtained above (in order to take into account the dimensions of the sample) by appropriate coefficient.
6. Read also the deformation at failure.
7. From the data, plot the following relationships:

   Density vs. bitumen content

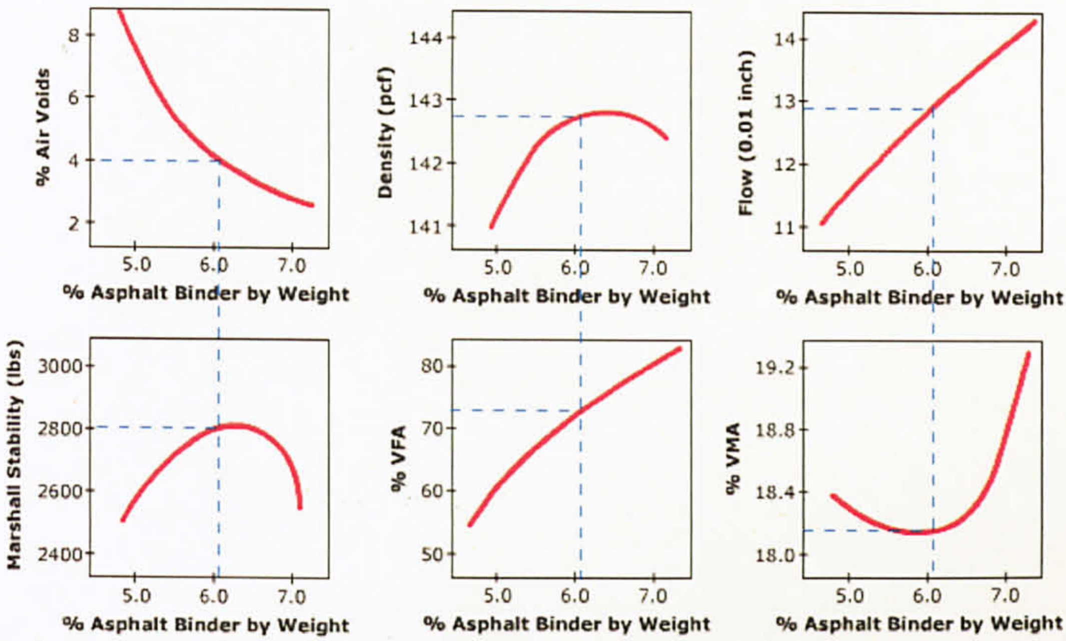
   Stability vs. bitumen content

   Porosity vs. bitumen content

   Flow vs. bitumen content

8. In the light of the data obtained, make comments regarding the suitability of asphalt mixes use in road surfacings.

Result from the plot is supposed like below. Asphalt binder content is being selects corresponding to the 4% air voids. The values of the other properties are being determine at this % asphalt binder and ensure they are within specification.



3.4 Indirect Tensile Stiffness Modulus (ITSM)

A repeated load is applied along the vertical Ø of a cored or laboratory moulded specimen at various frequencies and magnitudes. The resultant horizontal (indirect) deformations are measured and used to provide a measure of stiffness. In Europe the test is mainly used as a rapid method of quality control but it can also be used for a variety of other purposes including failure investigation. Similar tests to measure resilient modulus were detailed in ASTM and AASHTO standards.

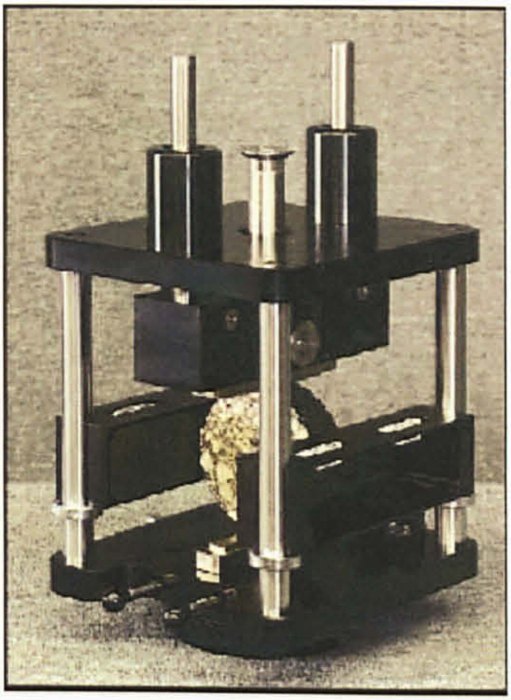


Figure 4: Indirect Tensile Testing Fixture

3.5 Beam Fatigue Test (BFT)

Flexural beam fatigue testing of asphalt mixtures has been used for nearly 40 years in the pavement industry. Since the development of the test, the definitions of initial and failure stifnesses have not been verified or validated in any comprehensive study. The main objective of this study is to validate the criteria used to define the initial and the final stiffnesses in flexure fatigue testing. In this study, extensive flexure fatigue tests were performed on five typical dense-graded mixtures and an asphalt rubber gap-graded mixture. An optimization approach was used, in which different intial and failure conditions were assumed. Fatigue models were developed using linear regression curve fitting and the conditions that produced the best fit were selected. Both the phenomenological and the dissipated energy approaches were used.

Test results conclusively indicated that the initial stiffness should be defined at cycle number 50. In addition, when a phenomenological approach for fatigue is employed, the fatigue stiffness should be taken at 50% of the initial stiffness. A stiffness degradation model was developed, which provided an independent proof that failue occurs when the stiffness of the beam is reduced to 50% of the initial stiffness. This model represents a basic material propertey at which damage accumulation in the mixture has produced an inability of the mix to resist further damage independent of the mode of loading. In contract to the tensile strain-failure approach, data analysis with the energy approach showed that fatigue failure stiffness, taken at 30% of the initial stiffness, provided identical fatigue energy failure regardless of constant stress or strain mode of loading. The results show that the phenomenological and energy approaches provide different definition of failure and the test should be consistent with the method of analysis used.

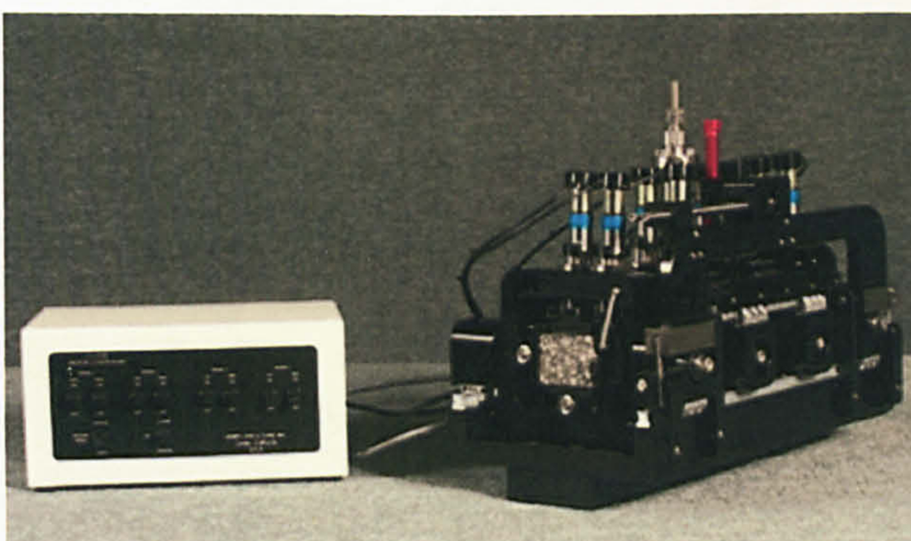


Figure 5: Asphalt Fatigue Testing Fixture

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Sieve Analysis

The result obtain will be recorded into Table below :

BS Sieve Size	Weight Retained (g)	Percentage Retained (%)	Total Passing (%)
28.00 mm	0	0	100
20.0 mm	24	2	98
14.00 mm	144	12	86
10.00 mm	144	12	74
5.00 mm	228	19	55
3.35 mm	156	13	42
1.18 mm	216	18	24
425 µm	84	7	17
150 µm	84	7	10
75 µm	48	4	6
Pan	72	6	0
Total	1200	100	100

Table 1 Sieve Analysis Result

By using the data from the table, graph Total Passing (%) versus Sieve Size (mm) will be plotted. If the graph obtained is not smooth enough, some modification of gradation or amount of the aggregate can be done in order to get a nice curve of gradation. The graph is attached to the appendices.

4.2 Specific Gravity and Water Absorption Test

Specific gravity is defined as ration 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.

Properties	**Coarse Aggregate**		**Fine Aggregate**
	Recycle Concrete	Limestone	
Specific gravity	2.11	2.50	2.79
Water absorption (%)	3.85	3.17	0.65

Table 2 Particle Density and Water Absorption value for coarse and fine aggregate

Table 2 shows the result of particle density and water absorption of both coarse and fine aggregates. The results for limestone are taken from Noraihan M.Y. (2008) research .The specific gravity of fine aggregates sample is 2.79. Specific gravity for recycle concrete is 2.11, slightly lower than limestone which is 2.50. From the result, it is clearly shown that limestone is denser than recycle concrete. This might due to structure of the aggregate itself. The structure of recycle concrete must have been not so solid after being hacked. These lead to a very high porosity of the rock. However, limestone consists of low porosity as the result of solidification process during the rock formation.

Water absorption value of the sand sample is 0.65. 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. However, for the coarse aggregates, recycle concrete and 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 fills in the pore spaces within the rock. It is known that the aggregate with higher water absorption value are porous and thus weak. So from the water absorption value obtain, it can be concluded that recycle concrete has higher porosity and weaker than limestone.

4.3 Marshall Test

The results for limestone are taken from Noraihan M.Y. (2008) research. 15 samples of bituminous mixtures with recycle concrete aggregates type were prepared. The samples were then being test 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 the obtained by multiplying its average specific gravity by the density of water γw.
Others properties of the mix also calculated such as VMA (% voids in compacted mineral aggregates) and also porosity.

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

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

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

4.3.1 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.

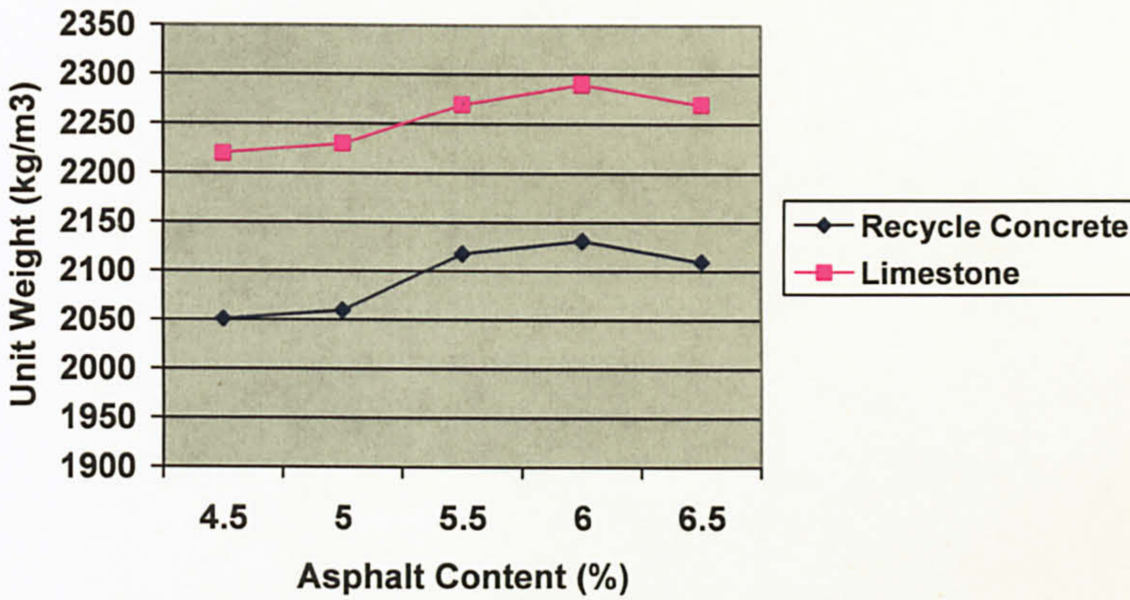


Figure 6: Unit Weight versus Asphalt Content

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 6 shows the unit weight or density curves for each bituminous mixture.

The samples were compacted using Marshall compactor. Recycle concrete has lower unit weight. This is because some of the aggregate that crushed were consisted of cement particles. As the cement crushed, it contributes to the aggregate in the middle size range, with the same amount of finer aggregate in the mixture. The mixture will has high porosity as the aggregate is not much to fill in the voids. It can conclude that compaction does have a very significant effect on the porosity and also unit weight of this mixture.

For the limestone, the unit weight is higher compared to recycle concrete is because the aggregate that been crushed only the mid size range and bigger which will be added to the existing finer sizes aggregate. All the smaller sizes aggregate will eventually filling the voids inside the mixture thus leads to low porosity. So during weighting the sample in the water, the weight of this sample will become higher than the recycle concrete which have high porosity. This will lead to higher unit weight or density of the limestone mixture.

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

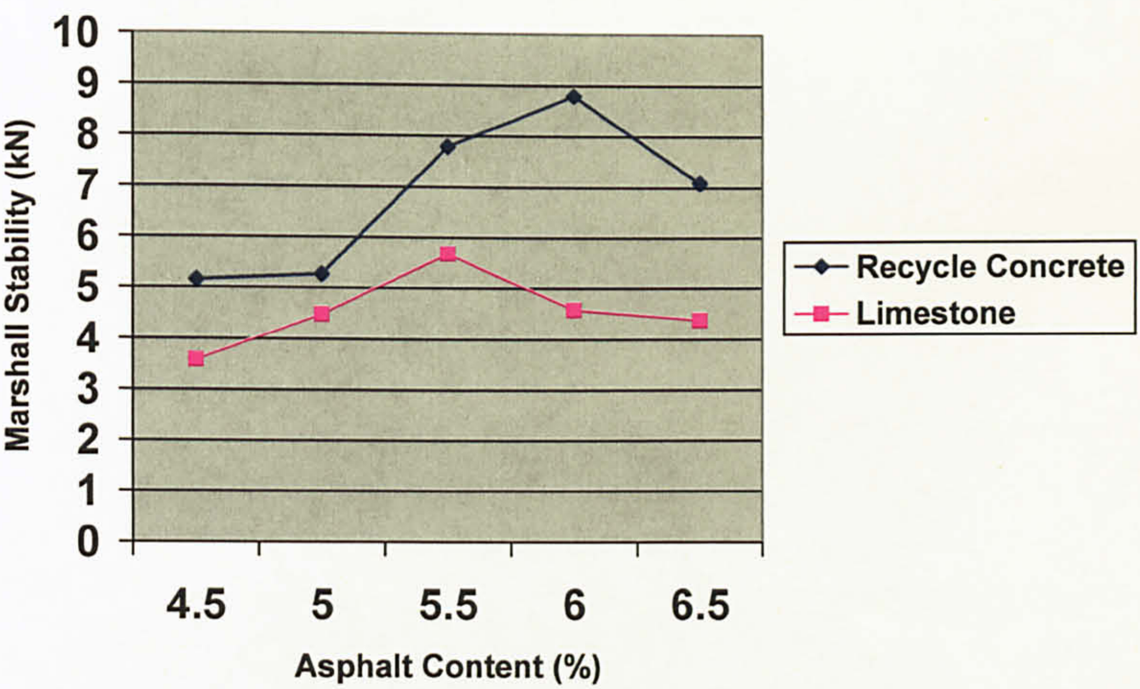


Figure 7: Marshal Stability versus Asphalt Content

Figure 7 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 recycle concrete shows higher than limestone. This means that the mixture has higher strength compare to the limestone.

The strength of recycle concrete contributes to the strength properties of the mixture. 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

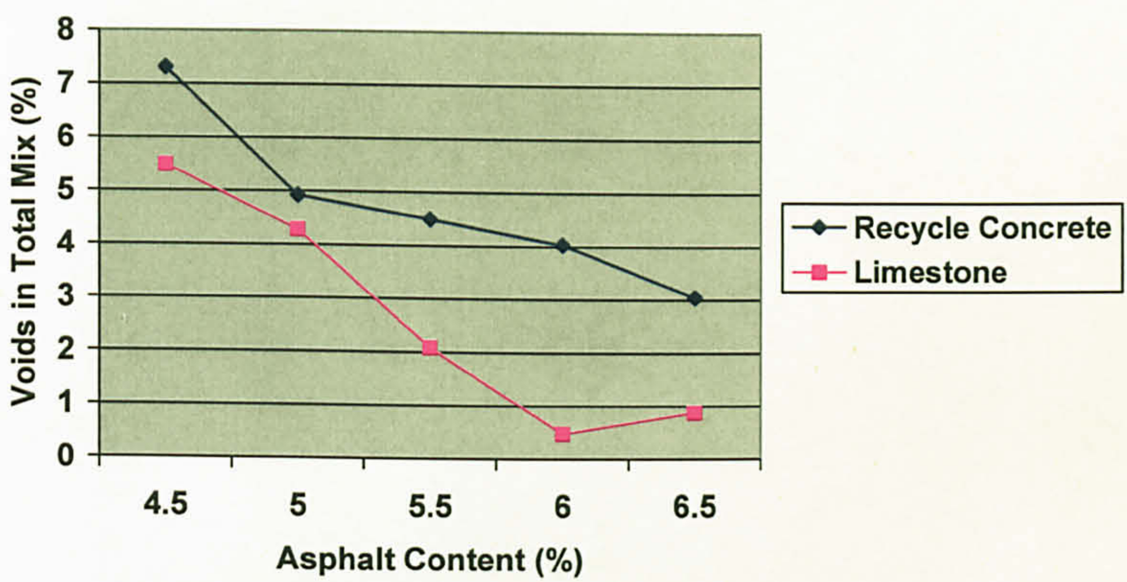


Figure 8: Voids in total Mix versus Asphalt Content

Figure 8 shows percent of voids in the 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 mixtures. Voids in total mix indicate the porosity of the mixture. As explained in the discussion of unit weight or density, the mixture of recycle concrete 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 limestone, it has lower porosity as more fine 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.

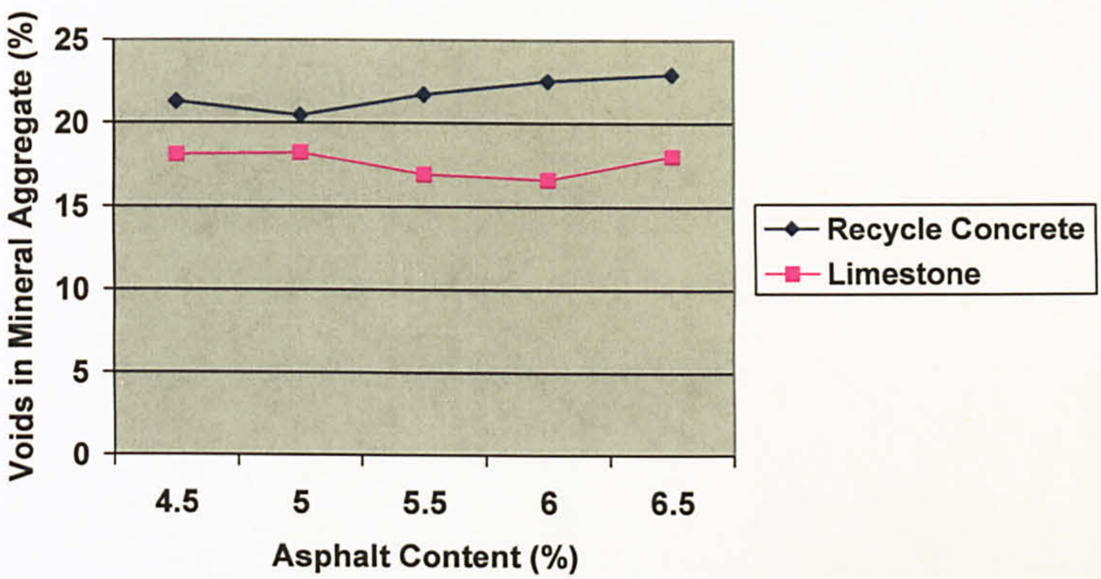


Figure 9: Voids in Mineral Aggregate versus Asphalt Content

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 Figure 9, Limestone has lowest VMA as the effect of compaction by the Marshall compactor. Recycle concrete shows higher VMA. This means that there are plenty of voids in the mineral aggregate itself.

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 content, the minimum values of

VMA of each mixture were considered. The reason is to minimize the voids in the mixture and in the aggregate itself.

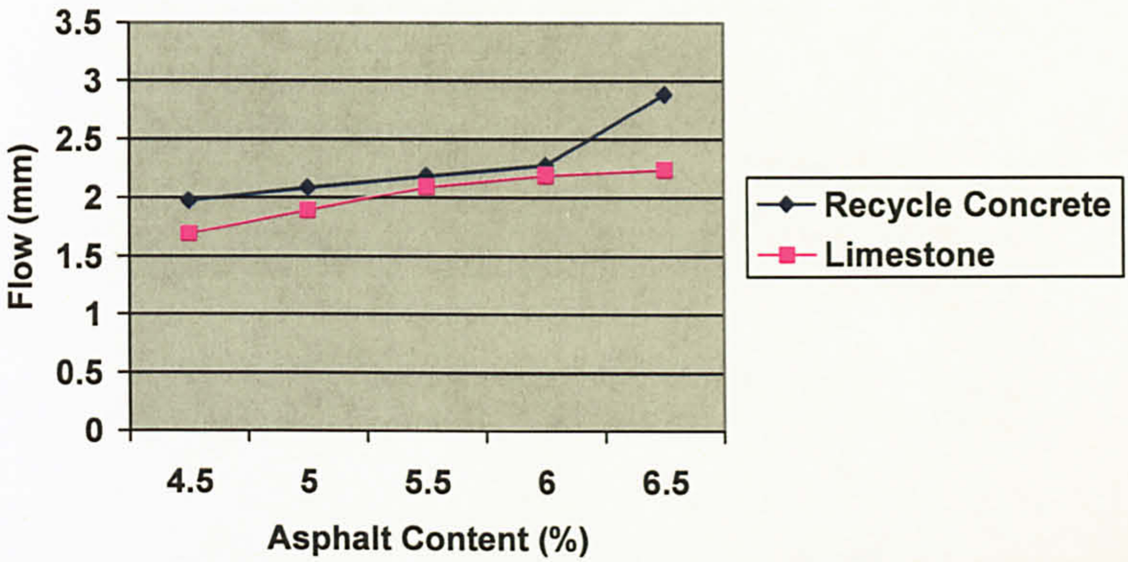


Figure 10: Flow versus Asphalt Content

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 10, it is shown that as the bitumen increased, the value of flow increased. Bituminous mixture of recycle concrete shows highest value of flow or deformation. This is because, the mixture requires more bitumen content compared to the limestone. The graph of flow does not considered in determining the optimum bitumen content mixture.

4.3.2 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 3 shows the summary of optimum binder content for the combination of bituminous mixture shown Appendix A.

Bituminous mixture	Optimum Binder Content
Recycle concrete	5.75
Limestone	5.63

Table 3 Optimum Binder Content for each bituminous mixture

4.4 Indirect Tensile Stiffness Modulus

The experiment is conducted by using indirect tensile testing machine. A total of 18 samples were tested and the results are shown in Figure 11.

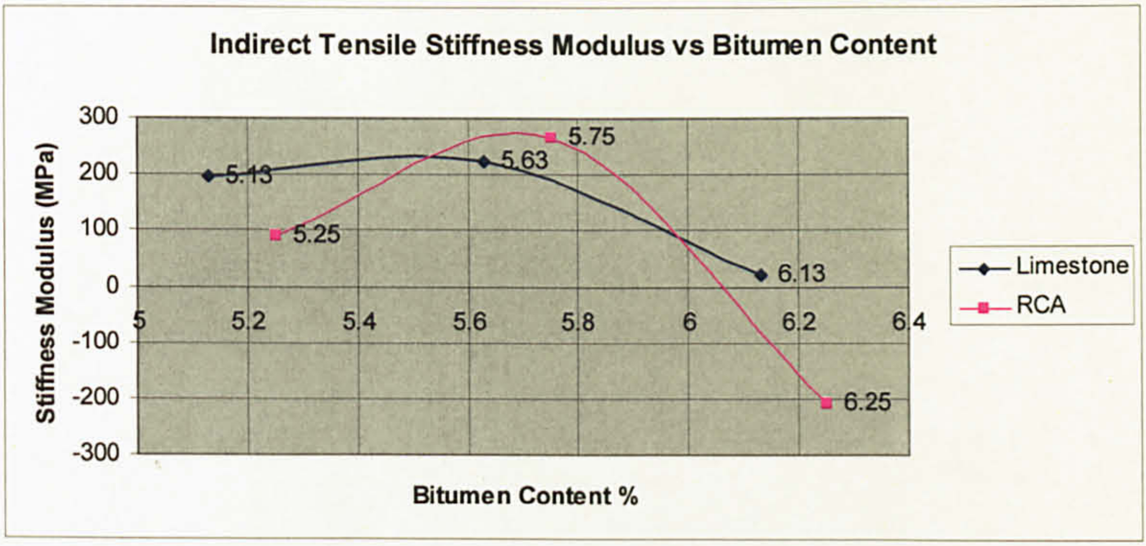


Figure 11: Indirect Tensile Stiffness Modulus versus Bitumen Content

From the Figure 11, its shows that all the mixes have definite optimum bitumen content for maximum stiffness modulus. The indirect tensile stiffness modulus increases with increasing bitumen content until an optimum value is reached after which the stiffness decreases with increasing bitumen content. The graph shows that the recycle concrete aggregates have higher value of stiffness than limestone. This may due to the strength and physical properties of recycle concrete aggregates. Mix with higher stiffness suggests that they are stiffer and more resistant to deformation.

4.5 Beam fatigue

The experiment is conducted by using beam fatigue testing machine. A total of 12 samples were tested and the results are shown in Figure 12

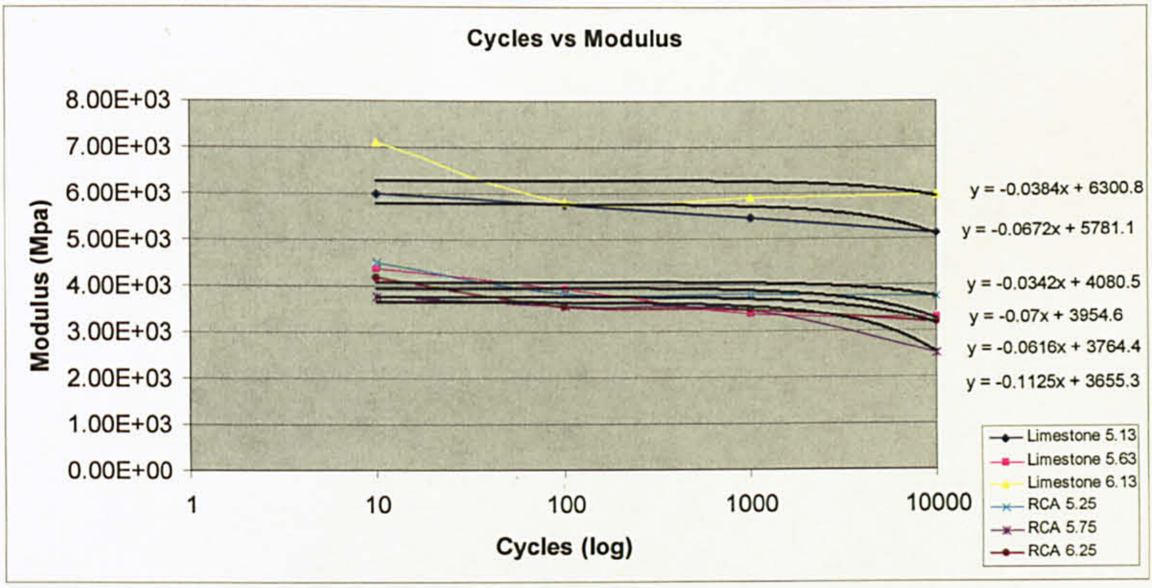


Figure 12: Cycles versus Modulus

In this experiment, the control mode is sinusoidal strain. In strain mode, the specimen will fail when the reading is half from the initial stiffness. Initial stiffness is the value at the 50 cycles. From Figure 12, the slope is being ranked. Table 4 shows the results.

Types of Aggregates	Equation	Slope	Overall Ranked Slope	Ranked slope by bitumen grade
Limestone 5.13	y= -0.0672x + 5781.1	-0.0672	3rd	2nd
Limestone 5.63	y = -0.07x + 3954.6	-0.07	2nd	1st
Limestone 6.13	y = -0.0384x + 6300.8	-0.0384	5th	3rd
RCA 5.25	y = -0.0342x + 4080.5	-0.0342	6th	3rd
RCA 5.75	y = -0.1125x + 3655.3	-0.1125	1st	1st
RCA 6.25	y = -0.0616x + 3764.4	-0.0616	4th	2nd

Table 4 Fatigue value ranked by slope

The slope from the equation determines the fatigue value of the sample. The lower the slope, the higher the fatigue value of the specimen. From the table, Recycle Concrete Aggregates have higher fatigue value than limestone. This is due to its physical properties.

Types of Aggregates	Cycles	Overall Ranked Cycles	Ranked cycles by bitumen grade
Limestone 5.13	35780	5th	3rd
Limestone 5.63	66925	3rd	1st
Limestone 6.13	56040	4th	2nd
RCA 5.25	32760	6th	3rd
RCA 5.75	96325	1st	1st
RCA 6.25	77480	2nd	2nd

Table 5 Fatigue value ranked by cycles

From the beam fatigue experiment, the cycles value for each sample until the experiment stops had been obtained. Table 5 shows the fatigue value of the sample ranked by the cycles until the experiment stops. Each specimen at their optimum bitumen content has the highest cycles. In table 5 are Limestone 5.63 and RCA 5.75. This shows that the specimen can sustain loads longer than other specimens. But, between Limestone and RCA, RCA have higher cycles than Limestone. This is due to it strengths and physical properties.

4.6 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.

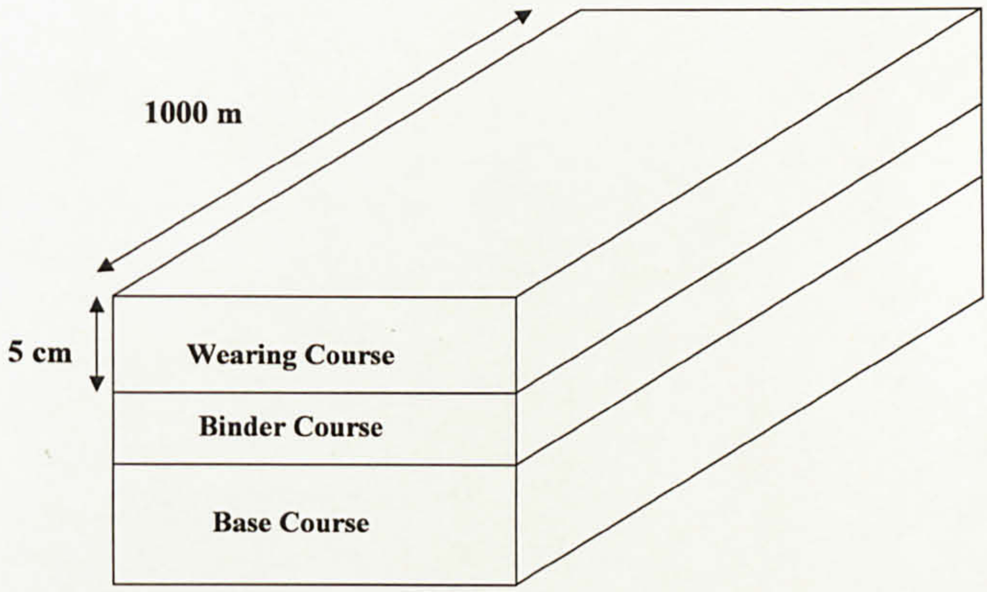


Figure 13: Cross Section of a Pavement

The calculation is only concentrated of the wearing course, with 5 cm (1.97 in) thickness and at a stretch of 1000m, as illustrated in figure 11. The following information was obtained from the recent price market.

Asphalt, RM 826 per ton

Coarse Aggregate (Limestone), RM 150 per ton

Coarse Aggregate (Recycle Concrete), RM 55 per ton

Fine Aggregate, RM 45 per ton

Multipliers are selected for each of the pay items and the calculations are like below:

I. Wearing Course (for limestone)

Coarse Aggregate: RM 150 per ton x 0.05 x 1.97 in. = RM15.07 per sq yd

Fine Aggregate: RM 45 per ton x 0.051 x 1.97 in. = RM4.52 per sq yd

Asphalt: RM 826 per ton x 0.003019 x 1.97 in = RM4.91 per sq yd

Total = RM24.50 per sq yd

Converting to m^2 = RM24.50 per sq yd x 0.83613 = RM20.50 per m^2

II. Wearing Coarse (for recycle concrete aggregate)

Coarse Aggregate: RM 55 per ton x 0.05 x 1.97 in. = RM5.42 per sq yd

Fine Aggregate: RM 45 per ton x 0.051 x 1.97 in. = RM4.52 per sq yd

Asphalt: RM 826 per ton x 0.003019 x 1.97 in = RM4.91 per sq yd

Total =RM14.85 per sq yd

Converting to m^2 = RM14.85 per sq yd x 0.83613 = RM12.42 per m^2

Bituminous Mixture	Cost (RM per m^2)	Total cost for 1000m stretch (RM / 1m width)
Limestone	2050	20500
Recycle Concrete Aggregate	12.42	12420

Table 6 Cost summary of the different Bituminous Mixture

Based on the cost summary in Table 6, it is clearly shown that mixture Recycle Concrete Aggregates provides the lowest cost. If considering the whole material cost, the cost bitumen alone does not have significant effect on the total cost. The most effecting factor is the cost of aggregate.

4.7 Summary of The Result

The Recycle Concrete Aggregate seems to be better than Limestone Aggregates. It is verified from the previous test on aggregate (Marshall Test, Indirect Tensile Test and Beam Fatigue Test) that Recycle Concrete Aggregate has higher strengths compare to limestone. Plus, in term of cost, Recycle Concrete Aggregate will be better because Limestone has higher market value compare to Recycle Concrete Aggregate.

Aggregate types also play an important role as a good aggregate can produce a strong and economical bituminous mixture. Recycle Concrete Aggregates have higher void in the aggregates than Limestone thus have higher porosity of the mix. From the result, it is proved that Recycle Concrete Aggregates is better than Limestone. In term of cost, Recycle Concrete Aggregates also shows better performance as it market value is lower than Limestone.

CHAPTER 5
CONCLUSION

The early stage for this project was more on investigating the properties of tensile and fatigue properties for bituminous mixture. The materials include aggregates which are recycle concrete aggregates and limestone, bitumen and filler. This purpose was achieved by conducting experiments in the lab and comparing the values of the properties obtained with the requirement from the JKR.

I. From the result of particle density test, it is found that limestone is denser than recycle concrete aggregates. This might due to structure of the aggregate itself. The structure of recycle concrete must have been not so solid after being hacked. These lead to a very high porosity of the rock.

II. Recycle Concrete Aggregates 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 recycle concrete has higher porosity than limestone.

Marshall Method was used in order to determine the optimum bitumen content between two different types of aggregates. From the experimental results, it was proved that recycle concrete aggregate produced the most optimum bitumen content.

I. Recycle Concrete Aggregates has the higher stability value than Limestone. It means that the mixture containing limestone aggregate has lower strength and it is not recommended to be used as the pavement material.

II. The flow values for Limestone are lower than Recycle Concrete Aggregates. 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 recycle concrete aggregates and limestone aggregates in term of percentage of voids in the total mix, recycle concrete aggregates have higher value than limestone. Limestone aggregates have very low voids, since those mixtures contain high percentage of finer aggregate tat 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.

Indirect tensile stiffness modulus and beam fatigue tensile test was used in order to determine the tensile and fatigue properties of the bituminous mixture. From the experimental result, it was proved that recycle concrete is better than limestone.

I. The Recycle Concrete Aggregates have higher value of stiffness than limestone. This may due to the strength and physical properties of recycle concrete aggregates. Mix with higher stiffness suggests that they are stiffer and more resistant to deformation.
II. Recycle Concrete Aggregates have lower slope value in equation and higher cycles value than Limestone. This shows that recycle concrete aggregates has higher fatigue value than limestone. This is due to its strengths and physical properties.

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 aggregates for the used in highway construction material.

I. From the analysis, Recycle Concrete aggregate shows more economical price compared to limestone aggregates.

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. From this project, recycle concrete aggregate proved to have greater performance compared to limestone.

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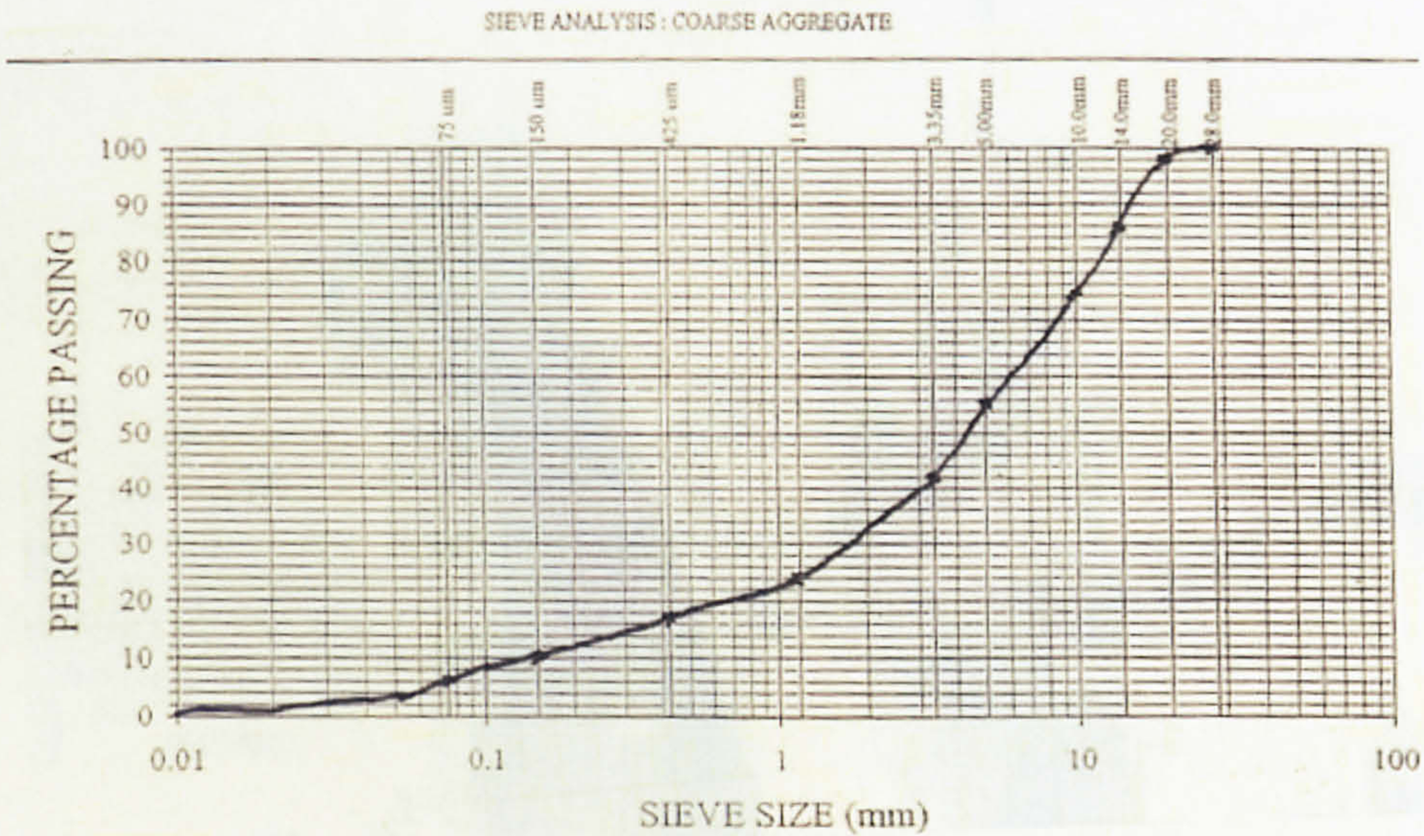
APPENDICES

APPENDIX A


SIEVE ANALYSIS : COARSE AGGREGATE
75 um
150 um
425 um
1.18mm
3.35mm
5.00mm
10.0mm
14.0mm
20.0mm
PERCENTAGE PASSING
100
90
80
70
60
50
40
30
20
10
0
0.01
0.1
1
10
100
SIEVE SIZE (mm)

APPENDIX B
RESULT FROM MARSHALL TEST FOR LIMESTONE AND RECYCLE CONCRETE

FYP2 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	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
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

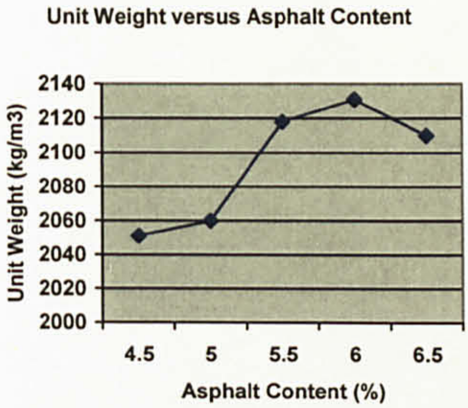
FYP2 MARSHALL MIX DESIGN & TEST (RECYCLE CONCRETE)

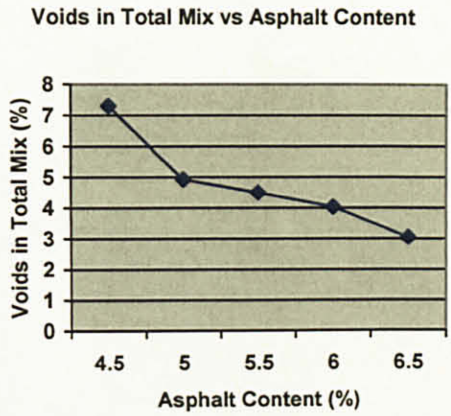
Bitumen Grade: _80/100__ Specific Gravity of Bitumen: __1.03__ Specific Gravity of Recycle Concrete: ___2.11___
Aggregate Gradation: _Well Graded_ Coarse Agg: _58_%, _696_g Fine Agg: _36_%, _432_g Filler: _6_%, _72_g

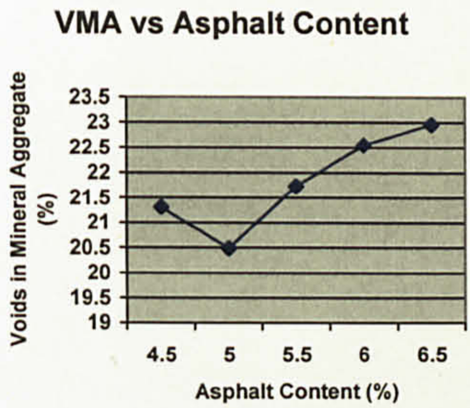
Binder content	Sample No.	Height	Mass of specimen		Volume (cm³)	Specific Gravity		Air Voids (%)		Flow (mm)	Stability (kN)		
			In Air (g)	In Water (g)		Bulk	Theory	Total Mix	VMA		Measured	C.F.	Corrected
4.5%	1	74.29	1200.5	606.5	607.1						6.60	0.78	5.148
	2	72.34	1226.5	575.5	616.9	1.90	2.05	7.31	21.31	1.98	4.14	0.81	3.353
	3	74.67	1246.5	590.0	614.4						8.96	0.78	6.989
5.0%	1	76.29	1203.5	585.5	615.3						6.86	0.76	5.214
	2	75.60	1223.5	606.5	617.7	1.93	2.03	4.93	20.49	2.09	6.41	0.76	4.872
	3	74.15	1237.5	600.0	606.3						7.36	0.78	5.741
5.5%	1	74.72	1203.5	559.0	610.4						9.11	0.78	7.106
	2	73.25	1260.5	611.0	599.0	1.91	2.00	4.50	21.73	2.19	10.72	0.78	8.362
	3	72.09	1254.5	605.0	589.0						9.78	0.81	7.922
6.0%	1	74.47	1271.0	612.5	602.1						11.39	0.78	8.884
	2	73.36	1252.0	602.5	599.8	1.90	1.98	4.04	22.55	2.28	10.91	0.78	8.510
	3	72.91	1234.0	591.5	595.7						11.11	0.81	8.999
6.5%	1	72.54	1245.5	601.0	613.5						8.04	0.81	6.512
	2	72.58	1259.0	604.5	616.7	1.90	1.96	3.06	22.96	2.89	9.10	0.81	7.371
	3	72.71	1246.0	596.5	594.1						9.14	0.81	7.403

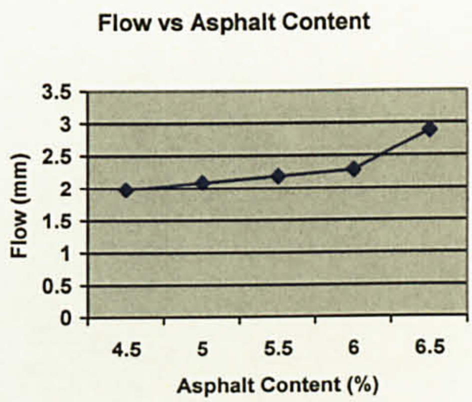
APPENDIX C
MARSHALL TEST PROPERTY CURVES

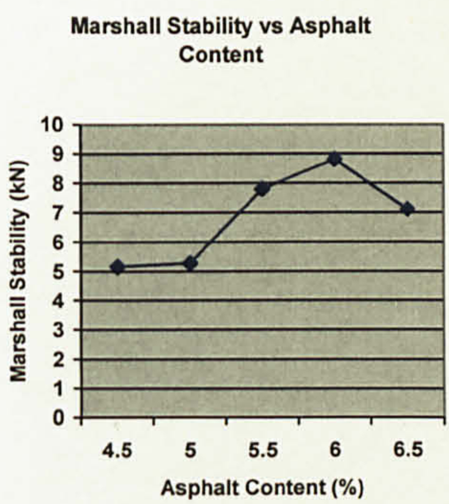
i. **Bituminous mixture of recycle concrete**









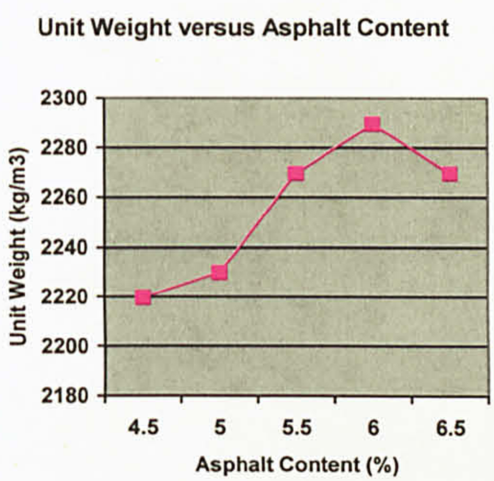


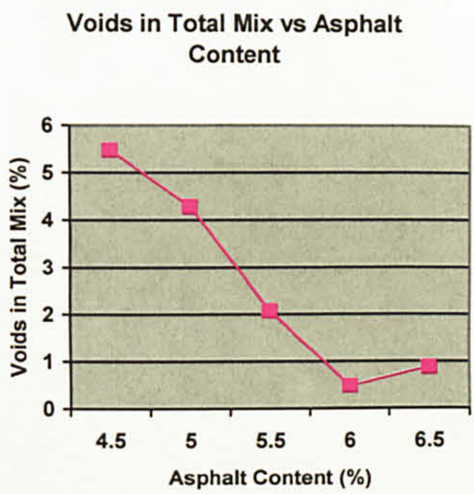
1. Maximum unit weight = 6.0
2. Maximum stability = 6.0
3. Minimum VMA = 5.0
4. Air voids in total mix at 4% = 6.0

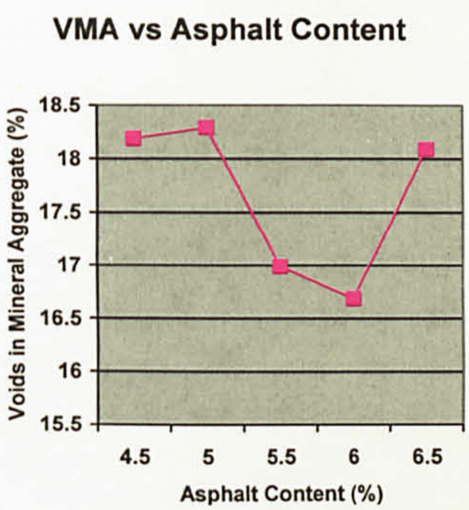
The optimum asphalt content is determined as the average:

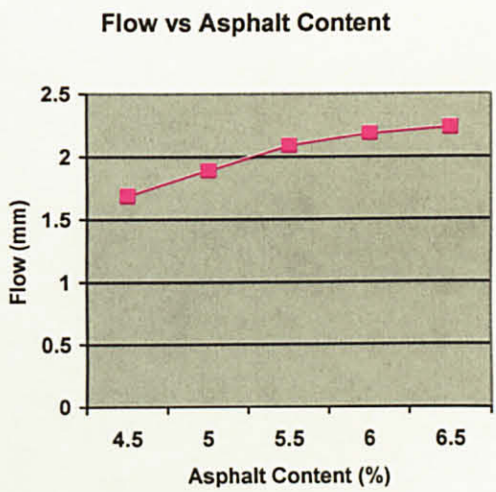
$$\frac{6.0 + 6.0 + 5.0 + 6.0}{4} = 5.75\%$$

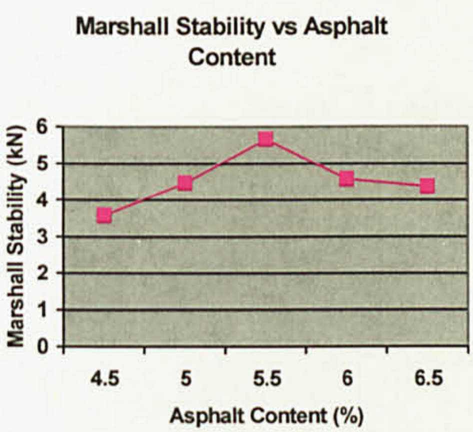
ii. **Bituminous mixture of limestone**











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:

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

APPENDIX D
INDIRECT TENSILE STIFFNESS MODULUS RESULTS

i. Limestone

Sample	Total resilient modulus (MPa)					
	Pulse 1	Pulse 2	Pulse 3	Pulse 4	Pulse 5	
1	218	-705	247	455	643	
2	301	-1021	319	664	853	Total average
Average	259.5	-863	283	559.5	748	197.4

Limestone 5.13

Sample	Total resilient modulus (MPa)					
	Pulse 1	Pulse 2	Pulse 3	Pulse 4	Pulse 5	
1	147	-294	142	191	257	
2	226	-648	575	706	926	Total average
Average	186.5	-471	358.5	448.5	591.5	222.8

Limestone 5.63

Sample	Total resilient modulus (MPa)					
	Pulse 1	Pulse 2	Pulse 3	Pulse 4	Pulse 5	
1	218	-705	101	147	197	
2	246	-693	195	235	291	Total average
Average	232	-699	148	191	244	23.2

Limestone 6.13

ii. Recycle Concrete Aggregate

Sample	Total resilient modulus (MPa)					
	Pulse 1	Pulse 2	Pulse 3	Pulse 4	Pulse 5	
1	364	-1291	163	194	701	
2	157	-681	322	440	546	Total average
Average	260.5	-986	242.5	317	623.5	91.5

Recycle Concrete Aggregate 5.25

Sample	Total resilient modulus (MPa)					
	Pulse 1	Pulse 2	Pulse 3	Pulse 4	Pulse 5	
1	245	146	398	149	257	
2	392	236	558	191	100	Total average
Average	318.5	191	478	170	178.5	267.2

Recycle Concrete Aggregate 5.75

Sample	Total resilient modulus (MPa)					
	Pulse 1	Pulse 2	Pulse 3	Pulse 4	Pulse 5	
1	536	-2544	19	92	220	
2	773	-1472	54	110	135	Total average
Average	654.5	-2008	36.5	101	177.5	-207.7

Recycle Concrete Aggregate 6.25

APPENDIX E
BEAM FATIGUE RESULTS

i. Limestone

Cycles	Modulus		
	Sample 1	Sample 2	Average
10	6.57E+03	7.63E+03	7.10E+03
100	6.34E+03	5.28E+03	5.81E+03
1000	6.43E+03	5.38E+03	5.91E+03
10000	5.94E+03	5.98E+03	5.96E+03

Limestone 5.13

Cycles	Modulus		
	Sample 1	Sample 2	Average
10	6.57E+03	7.63E+03	7.10E+03
100	6.34E+03	5.28E+03	5.81E+03
1000	6.43E+03	5.38E+03	5.91E+03
10000	5.94E+03	5.98E+03	5.96E+03

Limestone 5.63

Cycles	Modulus		
	Sample 1	Sample 2	Average
10	6.40E+03	5.59E+03	6.00E+03
100	6.09E+03	5.44E+03	5.77E+03
1000	6.06E+03	4.90E+03	5.48E+03
10000	4.71E+03	5.55E+03	5.13E+03

Limestone 6.13

ii. Recycle Concrete Aggregate

Cycles	Modulus		
	Sample 1	Sample 2	Average
10	6.57E+03	7.63E+03	7.10E+03
100	6.34E+03	5.28E+03	5.81E+03
1000	6.43E+03	5.38E+03	5.91E+03
10000	5.94E+03	5.98E+03	5.96E+03

Recycle Concrete Aggregate 5.25

Cycles	Modulus		
	Sample 1	Sample 2	Average
10	6.57E+03	7.63E+03	7.10E+03
100	6.34E+03	5.28E+03	5.81E+03
1000	6.43E+03	5.38E+03	5.91E+03
10000	5.94E+03	5.98E+03	5.96E+03

Recycle Concrete Aggregate 5.75

Cycles	Modulus		
	Sample 1	Sample 2	Average
10	6.40E+03	5.59E+03	6.00E+03
100	6.09E+03	5.44E+03	5.77E+03
1000	6.06E+03	4.90E+03	5.48E+03
10000	4.71E+03	5.55E+03	5.13E+03

Recycle Concrete Aggregate 6.25