TENSILE AND FATIGUE PROPERTIES OF BITUMINOUS MIXTURES INCORPORATING DIFFERENT BITUMEN GRADES

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By

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CERTIFICATION OF APPROVAL

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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.

Muhd Aliff B Muhammad Suhaimi

ABSTRACT

Fatigue and tensile is a performance indicator for road pavement. A bituminous mixture that good in durability, strength and performance will give a long life span and low cost maintenances of the flexible pavement. For this project, it was deals with two types of bitumen which are 60/70 penetration grade and 80/100 penetration grade. The bituminous mixture design use is Marshall Mix design to perform Asphaltic Concrete and Hot Rolled Asphalt type of mixtures. The test was conducted in order to achieve the objective is Beam Fatigue test and Indirect Tensile Stiffness Modulus. From the result, it is shown that 60/70 pen grade bitumen indicates higher value in initial stiffness, modulus of elasticity and maximum tensile stress compare to 80/100 pen grade bitumen. However, bitumen 80/100 penetration grade demonstrate higher number of cycles compare to 60/70 penetration bitumen. Although the bitumen content for HRA mixture more higher from AC mixture, the stiffness of mortar give more influence in term of performance compare with the interlocking effect of aggregate. In term of construction, the HRA mixture would be more costly due to high bitumen content needed to be use but the maintenance may be lesser compare to AC mixture.

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LIST OF ABBREVIATIONS

ITMS	Indirect Tensile Modulus Stiffness
CA	Coarse Aggregate
FA	Fine Aggregate
AC	Asphaltic Concrete
HRA	Hot Rolled Asphalt
US	United States
UK	United Kingdom
PSI	Present Serviceability Index
LVDT	Linear Variable Differential Transducer

CHAPTER 1
INTRODUCTION

1.1 Background of Study

The performance of pavement depends on bituminous mixture that will be used. The bituminous mixture is comprised of aggregate of different types and gradation, appropriate bitumen grade that reflect the type of gradation of the aggregate used in the mixture. A good bituminous mixing will improve certain engineering properties and behaviour of the pavement. For a flexible pavement, the commonly type of bituminous mixture used in design are Asphaltic Concrete (AC) and Hot Rolled Asphalt (HRA). These two type of mixture can be differentiate from the aggregate gradation and grade of bitumen used.

Aggregate can be differentiated into three (3) major size which are coarse aggregate (CA), fine aggregate (FA), and mineral filler. Depending upon size of aggregate, they are classified as well graded and gap graded. For this project, both well graded and gap graded type of gradation are used, as different type of gradation of aggregate would give different properties in term of strength, durability and voids.

Asphaltic Concrete (AC) is a mixture that combines the material such as coarse aggregate, fine aggregate, mineral filler and bitumen. The grade of bitumen that is be used in the design is 80/100 penetration grade bitumen. The strength of the mixture comes from the interlocking effect of the aggregate. The well graded gradation of aggregate give the interlock strength that obtains from the skid resistance, hardness, flakiness and the aggregate impact value.

Hot Rolled Asphalt (HRA) mixture is a gap graded blend of coarse aggregate, sand, filler and bitumen. The bitumen grade that commonly use is 50 penetration bitumen grades. However, for author's project, bitumen 60/70 penetration is used as it is not available in the market. The strength of pavement comes from the stiffness of the mortar that is combination of bitumen and appropriate filler.

There are various types of pavement design which are Marshall Mix design, HVEEM design and Superpave design. However, the widely use design is Marshall Mix because the method is the most inexpensive, simple, convenient to use and control. Marshall Test results will interoperated the stability, flow, density, VMA (% voids in compacted minerals aggregates) and porosity that reflect with bitumen content.

In term of performance of road pavement, the aspects that involve are tensile and fatigue properties. According to Qudais and Shatnawi (2005), fatigue cracking frequently starts as micro-cracks that later develop to form macro-cracks that propagate due to tensile or shear stress, or combinations of both, causing disintegration and finally the failure of material because of unstable crack growth. Pavement serviceability is reduced as these cracks propagate and disintegrate occurs. Mixtures resistant to crack development propagation of cracks thus improve pavement performances [1].

Tensile properties indicate how the material will react as the force being applied in tension. A tensile test is a fundamental mechanical test, where a carefully prepared specimen is loaded in a controlled manner while measuring the applied load and the elongation of the specimen over some distance. Tensile tests are used to determine the modulus of elasticity, elastic limit, elongation, tensile strength, yield point, yield strength and other tensile properties.

By referring to Hartman et al. (2001), the indirect tensile test has been used commonly for the asphalt mixture evaluations and pavement analyses. The test is simple to perform and is considered by some to be effective at characterizing materials in terms of their fundamental properties. Laboratory compacted asphalt specimens are required to have homogeneous distributions of air voids, aggregate and asphalt binder. Air void content is controlled by the compaction effort and is one of the most important variables affecting the fatigue resistance of compacted bituminous mixtures. As a cylindrical specimen is the only shape that can be produced by all the major laboratory compaction methods, the present investigation assessed the influence of the compaction method on the structural integrity of bituminous mixtures by performing Indirect Tensile Fatigue Tests (ITFT) and Indirect Tensile Stiffness Modulus (ITSM) tests [2].

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

This project deals with experimental and analysis of different bitumen grade incorporating with different type of bituminous mixture to have a economical mix which offer better pavement performance. 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

Roads whether in the rural or in urban area are a major public asset, in all countries. In order to efficiently protect and provide a good pavement, the best design of bituminous mixture will be determined to achieve the target. However, by monitoring the pavement by visual inspection of the road structure alone is not sufficient. By monitoring, the result give very little information of important engineering properties of the pavement and very high cost per kilometre due to the sample has been carried out. Therefore, a critical analysis must be done before laying the pavement to make sure the life span of the pavement is maximized.

Asphalt pavements exhibit mainly two types of failure modes: rutting and fatigue cracking. Fatigue cracking is a phenomenon which happens as a result of the build-up of small irrecoverable strains induced in the outermost parts of a bituminous bound layer due to repetitive wheel load applications. For example, if small crack develop in the road surface it will allow water to enter. This water can cause the road surface to bulge, and then thaws, returning it to the original position. Over time, the road surface weakens and the hole expands in size with wear. As soon as the first vehicle crosses it, damage begins accumulating in a pavement. Over time, as the pavement is "flexed" by traffic up to 100 million or more times, the pavement will begin to break from fatigue. This damage typically starts as a single crack where the wheels run on the pavement. Over time, more of these cracks will appear and eventually join to form a distinctive cracking pattern that is often referred to as "alligator" or "chicken-wire" cracking. Once this type of cracking occurs, if the pavement is not promptly repaired, the structural integrity of the pavement is lost. Soon the pothole are being formed which allow to seep into the pavement cracks can accelerating the failure by softening the soil under the pavement.

Rutting also can happen when the pavements not properly design. This permanent deformation may happen in any layer of pavement that usually caused by consolidation or lateral movement of the materials due to traffic loading. This problem specifically may occur due to many reasons such as excessively high asphalt content, excessive mineral filler and insufficient amount of angular aggregate particles.

The pavement design also needs to be cost effectively in term of maintenances or expansion lanes. In that case, a critical analysis of various grades of bitumen with different type of bituminous mixture will gives extra information in term of engineering properties and economical.

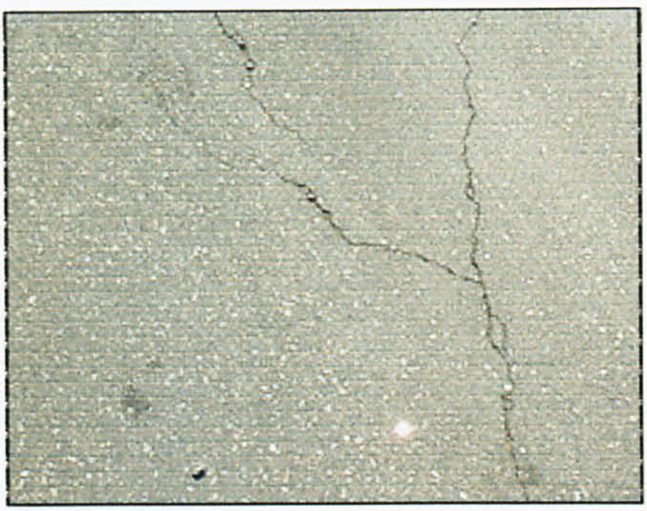

Figure 1 : Road Cracking

1.3 Objective

The main objective of this research is as below:

1. To obtain the effect of different bitumen grades on Hot Rolled Asphalt and Asphaltic Concrete corresponding with tensile and fatigue behaviours.

1.4 Scope of Study

The project basically focusing on three (3) elements which are the tensile and fatigue behaviour of bituminous mixture, various types of bituminous mixture and bitumen grades used in the mix. Thus, there a two type of bituminous mixture were prepared namely Asphaltic Concrete with 80/100 penetration bitumen grade and Hot Rolled Asphalt with 60/70 penetration bitumen grade.

The performance indicators for bituminous mixture can be obtained by determining its tensile and fatigue properties of the mixtures. To identify the tensile and fatigue parameters, laboratory test like Beam Fatigue test, Indirect Tensile Stiffness Modulus, and Indirect Tensile Fatigue Test were conducted on the prepared sample for both Asphaltic Concrete and Hot Rolled Asphalt.

CHAPTER 2

LITERATURE REVIEW

2.1 Definitions

Bituminous mixture design consist the determination of an economical blend and gradation of aggregates jointly with the optimum content of bituminous cement to produce durable mixture which would be stiff enough to resist traffic loads, workable for easy placement and convenient to compact.

Definitions:

i. Aggregate: Granular material of mineral composition such as sand, gravel, limestone, or crushed stone that used with a cementing medium to become mortar or concrete, or alone as in base course, railroad ballast, etc. (ASTM Designation D8-94)

ii. Coarse aggregate: A portion of aggregate that retained on the sieve 4.75 mm (No. 4) sieve (ASTM Designation C 125-93).

iii. Fine aggregate: usually will be appointed as sand which a loose, rounded to angular rock fragment that dimension about 1/1 to 2 mm (0.0025 to 0.08 in.) and for rounded fragments have the diameter around 0.074mm (no 200) sieve to 4.76mm (no 4) sieve.

iv. Gap graded aggregate gradation: The aggregate size distribution that partially or wholly absent of intermediate size portion.

v. Well graded aggregate gradation: The continuity appearance amount of aggregate for the whole size distribution.

vi. Fatigue cracking: "Phenomenon which happens as a result of the build-up of small irrecoverable strains induced in the outermost parts of a bituminous bound layer due to repetitive wheel load applications."(Khalid,2000) [3]

vii. Binder material: Material that have primarily of bitumen with strong adhesive properties, and dark brown to black colour ranging.(Garber and Hoel,2002) [4]

viii. Bituminous mixture: Mixture that comprise aggregates and bitumen.

(Garber and Hoel,2002) [4]

ix. Indirect Tensile Test: "The compressive loading of a cylindrical specimen along its vertical diameter to produce crack opening tensile stresses normal to the loading axis" (Hartman et al., 2001) [2]

2.2 Marshall Mix Design

"The mix design to determine the optimum bitumen content. There are many methods available for mix design which varies in the size of specimen, compaction, and other test specifications. Marshall Method of mix is the most popular design." (Mathew and Frishana, 2007) [5]

Basically, the bituminous design involve the selection of aggregate type, aggregate grading, the bitumen grade and optimum bitumen content that give the ultimate or maximize pavement service. In design methods, the optimum bitumen content is obtained from experimental works and critical analysis that have been done. Therefore, it is important to not underestimate the three (3) elements which are the type and gradation of aggregate and the bitumen content.

Marshall Mix design has been used widely compare to other method. However, there still other method and apparatus that be use such us The HVEEM method and other methods that involve with triaxial or creep test to determine the bitumen content.

Bruce Marshall on his original method states that the design bitumen content will give the peak of the unit weight versus bitumen content curve to check the bitumen properties with other desire standard.

In order to design a bituminous mix by laboratory procedures, with the aim of producing the required density and engineering properties, it is desirable to prepare specimens that reproduce material that will be use in field. The packing characteristics of the aggregates significantly influence the mix properties which cannot be assessed from grading curves, as these assume uniformity of particle shape, surface roughness and specific gravity.

Regarding to Hartman et al. (2001), evaluation of compacted specimens takes into account these aggregate compaction factors. Ideally specimen should be compacted at the same thickness as have been done in actual site; however, none of the bituminous design the procedure and the specimens will be compacted by hammer. By using hammer, the specimens not tend to be more anisotropic than using rolling technique [2].

2.3 Indirect Tensile Test

Several factors that affect the deterioration of roads are environment and traffic. A significant part of the damage on structural pavements is caused by cracking of the asphalt concrete layer. In that case, some cracking might be appear are fatigue cracking and low temperature cracking. Fatigue is considered to be one of the major distress modes in pavement, linked mainly due to repeated traffic load which leads to poor pavement performance, which in turn boosts maintenance as well as road user cost.

Khalid (2000) expressed that the indirect tensile test also known as diametral fatigue test. This test is conducted by repetitively loading a cylindrical specimen with a compressive load which acts parallel to and along the vertical diametral plane. The diametral fatigue test was develop and used in US and for UK's version it is called Indirect Tensile Fatigue Test (ITFT). The purpose of the test is to characterize the bitumen material in term of elastic stiffness. However, in order to perform the ITFT, the non-destructive ITSM test is required. By obtaining the ITSM at the indirect tensile fatigue test stress level, a graph of stiffness against stress is plotted and a linear regression is applied to obtain an equation relating the maximum tensile stress at the centre of the specimen, σ_{tmax} , to the ITSM. Such a relationship allows the calculation of the indirect tensile stiffness at any test stress (σ_{tmax}) level. Each specimen is then tested at a different target level of maximum tensile stress at the centre of the specimen in order that a corresponding differing number of fatigue lives to failure can be recorded [3].

Hartman, Gilchrist, and Walsh(2002) state that indirect tensile testing involves the compressive loading of a cylindrical specimen along its vertical diameter to produce crack opening tensile stresses normal to the loading axis. For highway pavement materials, the indirect tensile test is most usually used to determine static strength and stiffness modulus. At typical traffic speeds and pavement temperatures, asphalt behaves almost elastically and its elastic Indirect Tensile Stiffness Modulus (ITSM) is a measure of its resistance to bending and hence of its load spreading ability (Nunn and Smith 1996). Fatigue fracture under indirect tensile loading ideally should occur by bursting or splitting of the specimen in two half with minimum permanent deformation. Read (1996) indicated the possibility of localized shear and compressive failure near the loading areas at high temperatures and high stress levels. During the SHRP A-003A compaction study (Sousa et al. 1991), failure patterns were predominantly of three types: (i) crack initiation at or near the centre of the specimen, resulting in complete splitting of the specimen; (ii) crack initiation at the top of the specimen, progressively spreading downward in a V-shape, the arms of which originate from the outside edges of the loading platen; and (iii) no real cracking occurring, with the specimen being plastically deformed beyond the limiting vertical deformation [2].

The accumulation of permanent deformation is probably the biggest drawback of the indirect tensile fatigue test. This tends to hide the evidence of fatigue damage, and accordingly, the test does not characterize fatigue behaviour directly. This is particularly so at high temperatures, where nonlinear and visco-elastic material behaviour is more pronounced. The precision of the indirect tensile apparatus is heavily dependent on the accuracy with which the horizontal deformations are measured. The need to measure the deformation within the indirect tensile specimen has given rise to different fixtures that have been developed by various research institutions. These include strain gauges, an LVDT arrangement glued to the specimen, LVDTs mounted on columns that are independent of the specimen, extensometers clipping onto steel strips glued to the specimen sides, extensometers directly clipped onto the specimen, and micro-LVDTs that are fixed to the flat side of cylindrical specimens. The experiment will be operated according to the following standards: ITSM using BS DD 213 [British Standards Institution (BSI) 1993b] and ITFT using BS DD ADF (BSI 1996).

2.4 Fatigue Properties

On the other side, fatigue will be measure to indicate the performance of the mixture. According to Benedetto et al (1998), a typical fatigue process for asphalt mixtures can be characterised by three distinct phases denoted Phase I, II and III, respectively. The first phase is characterised by a rapid increase in sample temperature. During this phase, the stiffness of the sample decreases due to both fatigue damage and temperature increase. The effect of heating is very difficult to separate from the fatigue damage during Phase I and therefore difficult to analyse. Phase II is characterised by a quasi-linear decrease in stiffness. At the beginning of the Phase III, the sample starts to collapse, often due to increased non-uniformity in strain field. The behaviour during such a three-step evolution of the stiffness can be very different for different temperatures and binder stiffness used [6].

According to Benedetto and Roche (1998), the test that usual done to describe fatigue of a specimen of material by repeated loadings, generally identical and records the number of cycles to failure of the specimen (or life duration). Failure is define by some specific criterion [6].

Khalid (2000) also stated that fatigue tests can be carried out in controlled stress (load) or controlled strain (deflection) modes. Each of these modes has been linked to a particular pavement construction and thus considered to represent realistic service conditions. In France, major studies have been carried out by the "Laboratoire Central des Ponts et Chausees" using cantilever and centre-point beam fatigue tests to assess the performance of newly developed asphaltic materials and compare their fatigue performance to that of reference mixtures. In these studies which lasted more than four years, fatigue data obtained from the two bending fatigue tests were used in pavement models to improve the current analytical pavement design procedure used in France and to assess the influence of test procedure on the resulting fatigue performance. The main findings of these studies were the confirmation of close agreement between laboratory and field performance of materials in fatigue, and that fatigue re-suks from the two tests, *i.e.* two and three-point bending, gave favourably comparable results on all the mixtures used in the study. It has, hence, become common practice to use bending fatigue tests to provide reliable data for the accurate assessment of bituminous materials fatigue behaviour for pavement design purposes [3].

CHAPTER 3
METHODOLOGY

Different bitumen grades for bituminous mixture will be evaluated to determine the tensile and fatigue properties. The gradation of the aggregate will be determined by perform sieving analysis. Marshall Mix design will be utilized in this project since the previous Optimum Bitumen Content (OBC) had been determined by using this method. The laboratory test that will be performed is Beam Fatigue test, Indirect Tensile Stiffness Modulus, and Indirect Tensile Fatigue Test.

3.1 Determination of Material Properties

All the materials used for this project would be determined by perform several tests. For the aggregate properties, test performed were specific gravity, water absorption, Los Angeles Abrasion Test and Aggregate Value Impact (AVI). For bitumen properties, laboratory test performed were Standard Penetration, Softening Point test, specific gravity and ductility test. To determine the properties of filler, specific gravity of OPC will be measure by using Ultrapycnometer 1000.

3.2 Marshall Mix Design

For Marshall Test specimens, approximately 1200 g of aggregates and filler is heated to a temperature of 100°C - 110°C. Bitumen is heated to a temperature of 150°C - 160°C. The heated aggregates and bitumen are thoroughly mixed at a temperature of 160°C. The mix is placed in a preheated mould and compacted by a rammer with 75 blows on either side. The weight of mixed aggregates taken for the preparation of the specimen may be suitably altered to obtain a compacted thickness of 63.5 +/-3 mm. Vary the bitumen content in the next trial by +0:5% and repeat the above procedure number of trials are predetermined. The prepared specimens are cooled down to room temperature as shown in Figure 2.

Figure 2 : Cylindrical Specimens

In order to determine the optimum bitumen content, the Marshall Mix Design is the most widespread in use currently. However, the Optimum Bitumen Content for granite type of aggregate had been determined by the other researcher (Noraihan, 2008) [8]. The percentage of 80/100 penetration bitumen grade that were used in the mix are 5.05, 5.55, and 6.05. For 60/70 penetration bitumen graded were used in the mix are 6.30, 6.80, and 7.30.

3.2.1 Materials Preparation

The preparation procedure is carefully specified and involves heating, mixing, compacting the bituminous mixtures. The granite (Coarse Aggregate) and sand (Fine Aggregate) is placed in the oven to make sure the aggregate completely dry before the mixing. The temperature applied to the oven about 110-110°C.

For this project, there are two type of gradation which is well graded and gap graded. The gradation comprise of filler, fine aggregate and coarse aggregate. The gradation of the aggregate for well graded and gap graded type of gradation are as shown in Table 1.

Table 1 : Percentage for Coarse, Fine and Filler for Well and Gap Graded

Material	Well graded	Gap Graded
Coarse Aggregate	42 %	35 %
Fine Aggregate	50 %	55 %
Filler	8 %	10 %

In order to obtain the necessary aggregate gradation, sieve analysis was done to separate the required sizes. Granite, sand and OPC were weighed to obtain 1.2 kg. For well gradation of aggregate, it shall conform to the appropriate envelope by JKR shown in Table 2.

Table 2 : Well Gradation Distribution for Asphaltic Concrete

B.S. Sieve Size (mm)	% Passing by Weight
37.5	100
28.000	100
20.000	100
14.000	95
10.000	90
5.000	72
3.350	58
1.180	35
0.425	20
0.150	10
0.075	8

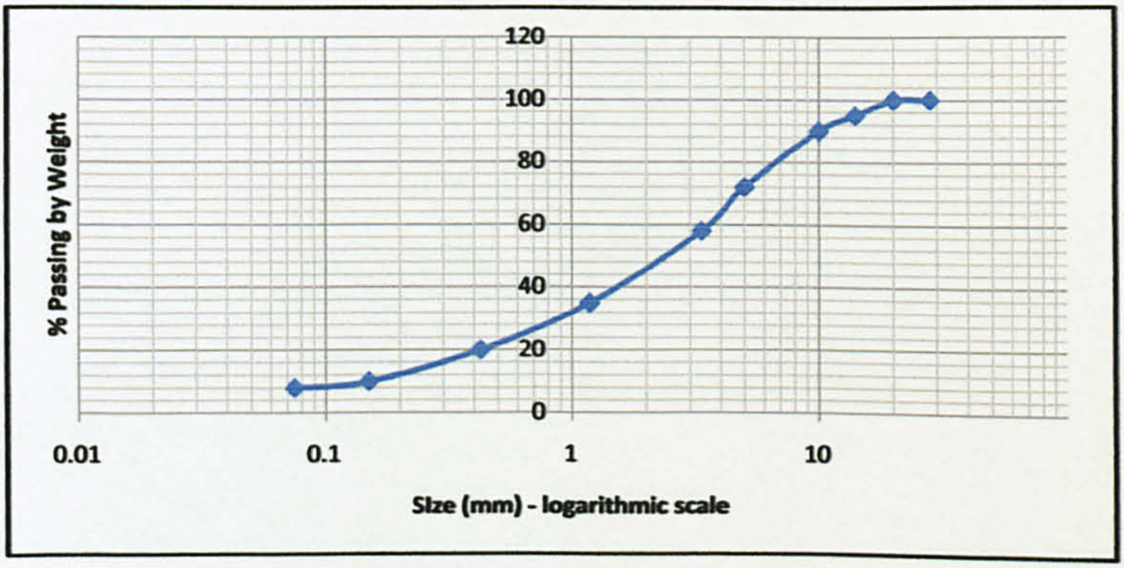

Figure 3 : Semi-log graph Well Graded distribution

Figure 3 shows the distribution of aggregate for Asphaltic Concrete mixture. The range of aggregate well gradation based on JKR standard as on APPENDIX A.

For Hot Rolled Asphalt mixture, gap gradation would be used. The gradation of the aggregate shown in Table 3.

Table 3 : Gap Gradation Distribution for Hot Rolled Asphalt

B.S. Sieve Size (mm)	% Passing by Weight
20.000	100.00
14.000	96.44
10.000	70.79
6.300	65.36
5.000	64.80
2.360	63.92
0.600	61.60
0.300	31.88
0.212	23.16
0.150	9.99
0.075	9.85

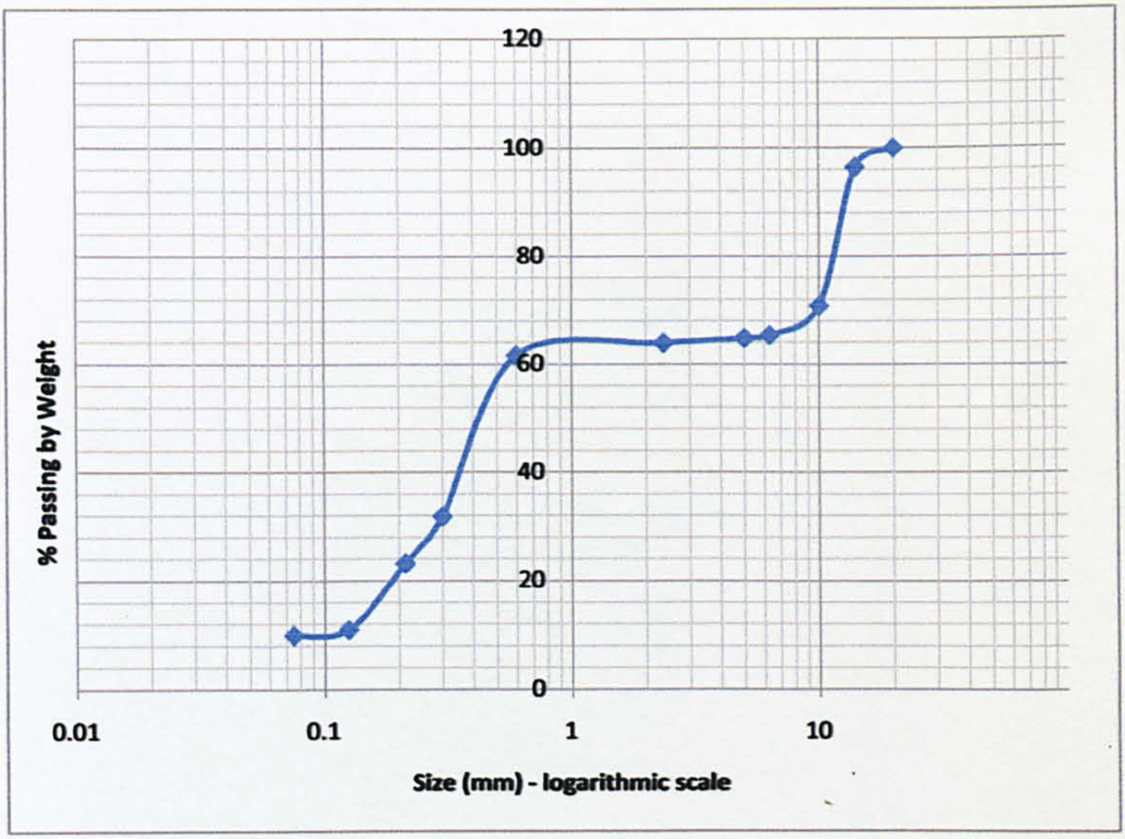

Figure 4 : Semi log graph Gap Graded distribution

Figure 4 shows the aggregate distribution for Hot Rolled Asphalt mixture.

Three (3) specimens need to be mix for each bitumen contents. For AC mixture, the bitumen contents that would be utilized are 5.05%, 5.55%, and 6.05%. On the other hand, HRA mixture would be deals with 6.3%, 6.8%, and 7.3% bitumen contents. Therefore, there would be nine (9) specimens for AC and nine (9) specimens for HRA. The total cylindrical specimens for this project are eighteen (18).

For Beam Fatigue Test, rectangular specimens need to be produce. By using 10 cm x 10 cm x 100 cm steel moulds, the author can produce two (2) specimens in one mould. After compact the mixture, the specimen need to be could down into room temperature for at least 12 hours in order to make a strong bonding between aggregate and bitumen. The 10 cm x 10 cm x 100 cm need to be cut into a specific size as shown in Figure 5.

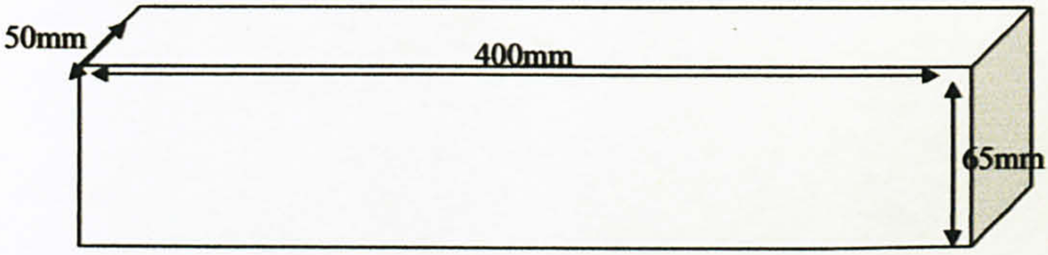

Figure 5 : Dimension of Beam Fatigue test specimen

3.3 Indirect Tensile Test

In the context of recent studies regarding performance that related mix design of the bituminous mixture with the fatigue performance can be obtain by indirect tensile test.

3.3.1 Indirect Tensile Stiffness Modulus (ITSM)

The ITSM test is to determine the stiffness modulus of the bituminous mixture sample. The appropriate temperature is 40°C which is the maximum temperature on the road. The durability of the bituminous mixing can be obtain that can resist from environment damage that cause by air and water.

The ITSM test is non-destructive test which the sample will not rupture. By referring to Neves and Gomes, the cylinder specimens were prepared will be measured the height and diameter. Before testing, test specimens were stored overnight inside the refrigerator incubator at the specified test temperatures in order to maintain the core and skin temperature of the specimens . All specimens were tested at 40°C. This temperature has been assumed as the maximum temperature on the pavement. Special procedures were adopted to provide the proper adjustment and to centre the specimen in the loading platens and in the deformation measuring device. A preliminary conditioning of five load pulses was applied to bed the test specimen on the loading platens and to enable the equipment to adjust the vertically applied load in order to give the specified horizontal diametral deformation. The loading test consists of sinusoidal load pulses characterized by the rise-time and peak value. Series of tests were performed for different values of rise-time and peak load pulse. For each load pulse, the peak load, peak horizontal diametral deformation and rise-time were recorded and the indirect tensile stiffness modulus was calculated according to the expression presented in computer programme. For each test performed in specified conditions of temperature, load peak and rise-time, a minimum of ten load pulses was applied in two or four diameters, depending on the degree of anisotropy of the material as indicated in British Standard test procedure [9].

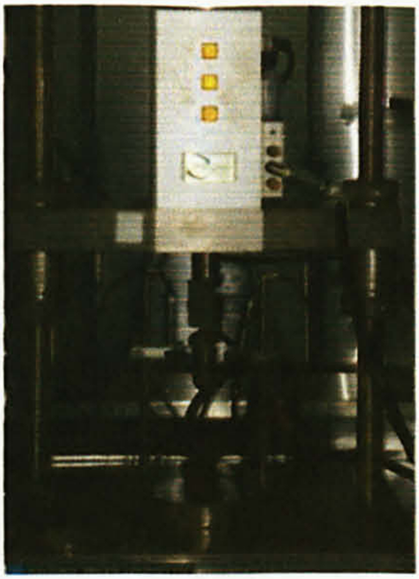

Figure 6 : Indirect Tensile Stiffness Modulus Machine

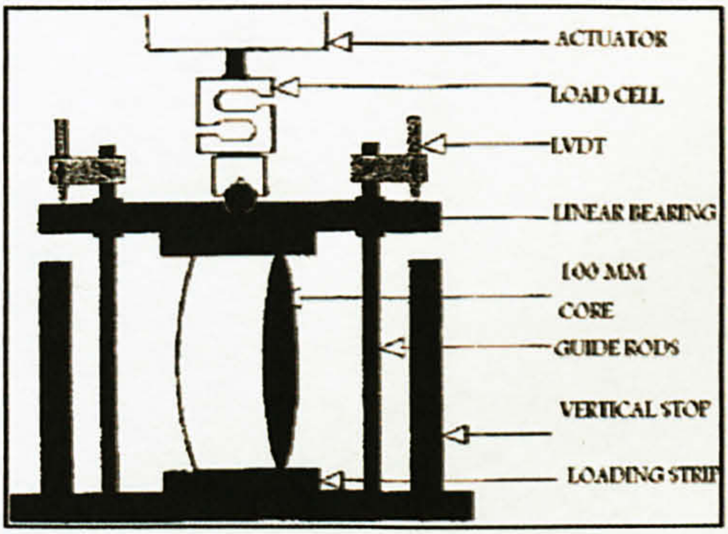

Figure 7 : Schematic for ITSM

3.4 Beam Fatigue Test

Application of Beam Fatigue Apparatus will be utilized to conduct this experiment. The Beam Fatigue test will determine the fatigue life of the pavement level. It is important to obtain the fatigue parameters because the result will indicate the performance of the bituminous mixture or the pavement. The test is subjected to flexural repeated loading in two modes of experiments. The tests based on constant strain/deflection or constant stress/load; both utilizing sine, square, triangular and user defined waveform. The Beam Fatigue Apparatus can perform the fatigue test in both modes at frequencies up to 10 Hertz. The equipment software's can capture every 10th cycle and deflection of beam specimen at the same time. With advance technology, the display can show the flexural stiffness, the beam deflection, force applied onto beam, the max tensile stress, max of tensile strain and by dissipated energy. The tabulated data can be calculated and show on the screen some result such as test duration, peak loading force, peak tensile stress and strain, loading cycle count, flexural stiffness, phase angle, and etc.

Figure 8 : Beam Fatigue test Specimen

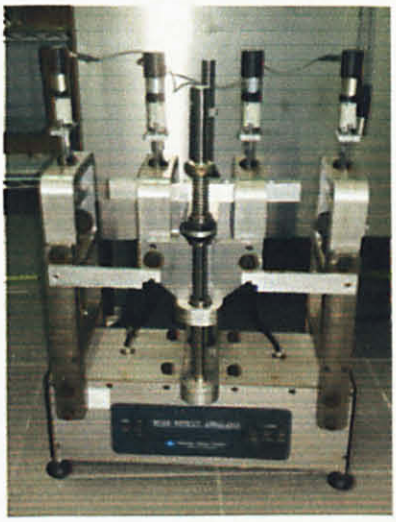

Figure 9 : Beam Fatigue Machine

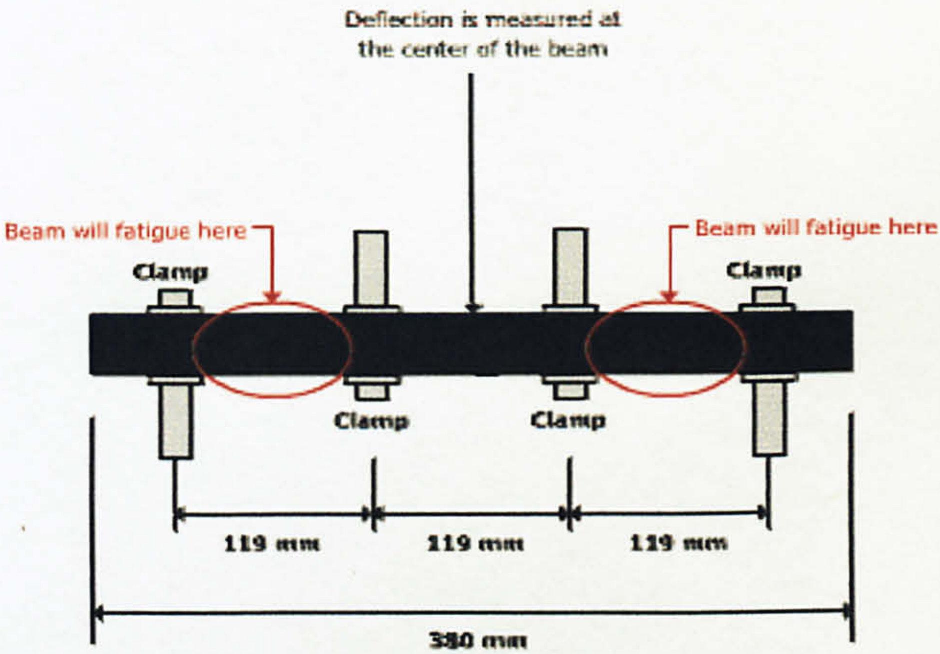

Figure 10 : Schematic for Beam Fatigue Test

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Material Properties

Lab test would be done in order to obtain the material properties of the coarse aggregate, fine aggregate, bitumen and OPC as mineral filler. These inputs were essential in order to ensure the material used are according to the standard that have been set by JKR.

4.1.1 Bitumen properties

This project deals with two different bitumen grades which are 80/100 penetration grade bitumen and 60/70 penetration grade bitumen. The laboratory test performed in order to evaluate both bitumen properties were penetration test, ductility test, softening point test and specific gravity test. The summary results were shown in Table 4

Table 4 : Comparison between Bitumen Properties and JKR Requirements

Bitumen grades	Unit	60/70	80/100	JKR Requirements
Penetration	0.1mm	68	93	
Ductility	cm	109.3	112.25	Not less than 100
Softening point	°C	52	48.3	Not less than 45 & not more than 52
Specific Gravity		1.04	1.03	Between 1.03 and 1.04

Based on the comparison above, all the bitumen properties lie within the allowable JKR Requirement. With these results, both 80/100 and 60/70 bitumen can be used in this project.

4.1.2 Aggregate properties

For this project, granite will be used as coarse aggregate and sand as fine aggregate. The mechanical and physical properties of aggregate would be investigate by perform several test. The laboratory tests were Specific Gravity, Water Absorption, LA Abrasion, and Aggregate Value Impact (AVI).

Table 5 : Comparison between Aggregate Properties and JKR Requirements

Properties	Unit	Coarse Aggregate	Fine Aggregate	JKR Requirements
Specific Gravity		2.46	2.58	
Water Absorption	(%)	1.1	0.51	Not more than 2
LA Abrasion	(%)	19.6		Not more than 60
AVI	(%)	24.8		9 to 35

Table 5 shows the summary of comparison between aggregate properties and JKR requirements. The results shows that all the properties were lie within the range that set up by the JKR. Therefore, the materials were appropriate to use in this project.

The mineral filler that were be used in the mixture is Ordinary Portland Cement (OPC). In order to determine the OPC properties, Ultrapycnometer 1000 was performed. The specific gravity for OPC is 3.32.

4.2 Marshall Mix Design

4.2.1 Material Preparation

The aggregate gradation used for mixing the bituminous was well graded and gap graded. Both gradations are combination of granite, sand and OPC. Sieve analysis would be performed to determine the gradation of the aggregate. There would be two types of specimen which are cylindrical and rectangular specimens. The cylindrical specimen would be test for Indirect Tensile test and rectangular specimens for Beam Fatigue test. The amount of aggregate needed for each cylindrical specimen would be determine in Table 6 and 7:

Table 6 : Quantity of aggregate needed for AC

B.S. Sieve Size (mm)	% Passing by Weight	% Retained on Rieve	Required Weight (g)
28.000	100	0	0
20.000	100	0	0
14.000	95	5	60
10.000	90	5	60
5.000	72	18	216
3.350	58	14	168
1.180	35	23	276
0.425	20	15	180
0.150	10	10	120
0.075	8	2	24
Filler	0	8	96
Total		100	1200

Table 7 : Quantity of aggregate needed for HRA

B.S. Sieve Size (mm)	% Passing by Weight	% Retained on Sieve	Required Weight (g)
20.000	100.00	0.00	0.00
14.000	96.44	3.56	42.72
10.000	70.79	25.65	307.80
6.300	65.36	5.43	65.16
5.000	64.80	0.56	6.72
2.360	63.92	0.88	10.56
0.600	61.60	2.32	27.84
0.300	31.88	29.72	356.64
0.212	23.16	8.72	104.64
0.150	11.00	12.16	145.92
0.075	10.00	1.00	12.00
Filler	0.00	10.00	120.00
Total		100.00	1200.00

In order to determine the bitumen content used for each specimen, the formula used: The quantity of bitumen for each cylindrical specimen would be summary in Table 8:

Table 8 : Quantity of Bitumen for cylindrical specimen

Bitumen Grade	Bitumen (%)	Total Weight of Specimen (g)	Bitumen Required (g)
80/100	5.05	1263.82	63.82
	5.55	1270.51	70.51
	6.05	1277.28	77.28
60/70	6.30	1280.68	80.68
	6.80	1287.55	87.55
	7.30	1294.50	94.50

In order to determine the material amount for rectangular specimens, the density of cylindrical specimen would be measure. Table 9 shows the summary of density for Asphaltic Concrete and Hot Rolled Asphalt.

Table 9 : Density for Asphaltic Concrete and Hot Rolled Asphalt

Bituminous Mixture	Asphaltic Concrete	Hot Rolled Asphalt
Density	1.9	2.0

The details of density calculation would be in APPENDIX C as references.

Based on the density value, the amount of coarse aggregate, fine aggregate, filler and bitumen were determine by calculation. The summary of the amount material needed for rectangular specimen shows in Table 10.

Table 10 : Amount of aggregate and bitumen needed for Beam Fatigue specimen

Bituminous Mixture	Bitumen Content	Amount (g)			
		CA	FA	Filler	Bitumen
AC	5.05	3987.9	4747.5	759.6	505.0
	5.55	3966.9	4722.5	755.6	555.0
	6.05	3945.9	4697.5	751.6	605.0
HRA	6.30	3115.5	4895.8	890.2	598.5
	6.80	3098.9	4869.7	885.4	646.0
	7.30	3082.3	4843.6	880.7	693.5

4.3 Indirect Tensile Stiffness Modulus

4.3.1 Test Result

ITSM was performed to determine the stiffness modulus of the bituminous mixtures. The test is a non destructive test and can be utilize again to measure the other side of specimen. Five load pulses were applied onto specimen and the result will be monitor by the programmed computer. The results for the test are presented in Table 11.

Table 11 : Resilient Modulus for each specimens

Bitumen grade	Bitumen Content (%)	Resilient Modulus (MPa)			
		Sample 1	Sample 2	Sample 3	Mean
80/100	5.05	291	237	-508	264.00
	5.55	322	317	369	336.00
	6.05	-23	138	240	189.00
60/70	6.3	447	95	343	395.00
	6.8	130	384	492	438.00
	7.3	264	257	-101	260.50

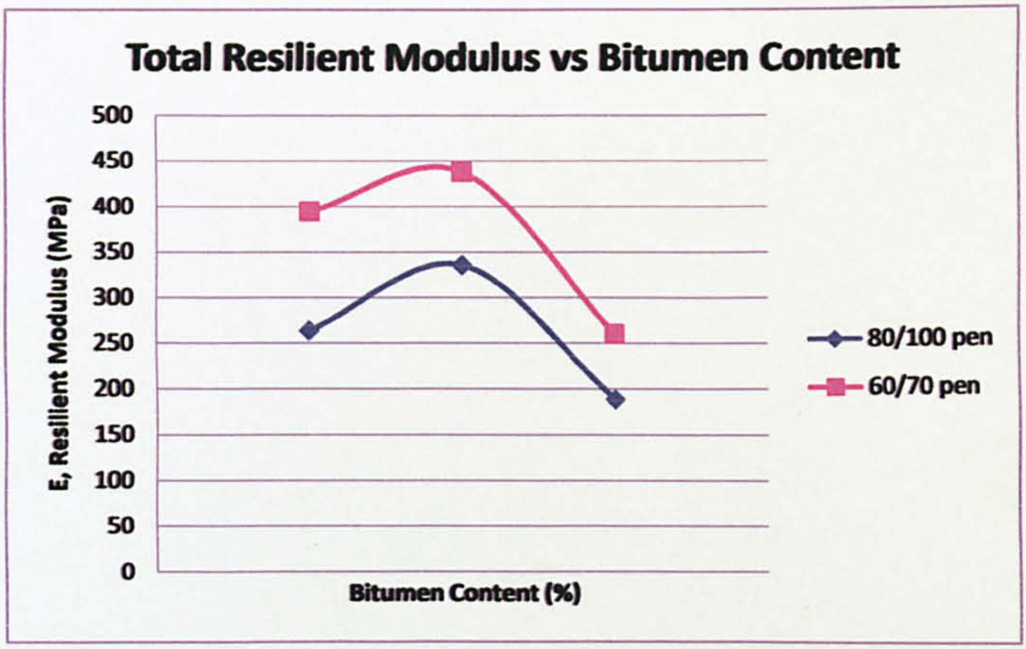

Figure 11 : Total Resilient Modulus vs Bitumen Content

Figure 11 represent the comparison between 60/70 pen bitumen grade and 80/100 pen bitumen grade for each Resilient Modulus values. From the graph, the Resilient Modulus value will increasing until a peak point and decreasing by bitumen content (%) for each grade. The patterns for both bitumen grades are quite similar. The similar pattern may shows that both mixtures have similar tensile properties.

It also shows that the maximum stiffness for each bitumen grade at OBC value. The OBC value may give higher stiffness value due to the optimum bitumen needed by the mixture to have good performance.

Bitumen 60/70 pen grade also indicate that the higher modulus value compare to 80/100 grade. It is shows that the stiffness for 60/70 pen grade bitumen is higher compare to 80/100 pen bitumen. The bitumen content for HRA may higher compare to AC mixture, however the bitumen stiffness may influence more the tensile properties.

4.4 Beam Fatigue Results

The rectangular specimens (5cm x 6.5cm x 40cm) were test by using Beam Fatigue machine test. The 4- point bending beam fatigue test would measure the fatigue life and tensile properties of the specimens. For this experiment, the sinusoidal strain control would be used and the temperature utilize was 20°C.

4.4.1 Test Result

The machine would automatically measure the output of the test. The parameter that been measure were cycle count, applied load, maximum load, minimum load, beam deflection, maximum tensile stress, initial stiffness, flexural stiffness, modulus of elasticity, phase angle, energy and the LVDT. The results would be summary in Table 12 and 13 for each specimen.

Table 12 : Asphaltic Concrete Test Result

Bituminous Mixture	Units	Asphaltic Concrete					
Bitumen Content	%	5.05		5.55		6.05	
Sample No.		1	2	1	2	1	2
Cycles Count	N	54250	307400	307490	230070	36190	24920
Applied Load	kN	0.149	0.323	0.224	0.2	0.24	0.281
Maximum Load	kN	0.158	0.092	0.167	0.158	0.202	0.125
Minimum Load	kN	0.009	-0.231	-0.057	-0.042	-0.037	-0.156
Beam Deflection	mm	0.061	0.056	0.06	0.053	0.062	0.054
Maximum Tensile Stress	kPa	375	697	586	634	617	590
Maximum Tensile Micro-Strain		103	102	101	98	105	102
Initial Stiffness	MPa	5971	5444	11741	5896	5439	5565
Flexural Stiffness	MPa	3635	6834	5791	4451	5870	5770
Termination Stiffness	MPa	2985	2722	5870	2948	2720	2783
Modulus of Elasticity	MPa	3831	7266	6106	4740	6192	6158
Phase angle	Degrees	28.7	28.6	36.5	37.6	-158.4	24.4

Table 13 : Hot Rolled Asphalt Test Result

Bituminous Mixture	Units	Hot Rolled Asphalt					
Bitumen Content	%	6.3		6.8		7.3	
Sample No.		1	2	1	2	1	2
Cycles Count	N	105440	40730	71050	49500	311130	8330
Applied Load	kN	0.222	0.354	0.484	0.481	0.327	0.402
Maximum Load	kN	0.163	0.343	0.444	0.171	0.27	0.253
Minimum Load	kN	-0.059	-0.011	-0.04	-0.31	-0.057	-0.149
Beam Deflection	mm	0.057	0.055	0.054	0.057	0.056	0.055
Maximum Tensile Stress	kPa	490	835	1118	1068	815	908
Maximum Tensile Micro-Strain		104	98	95	103	98	101
Initial Stiffness	MPa	9668	9344	9844	9311	8830	8819
Flexural Stiffness	MPa	4714	8482	11772	10404	8314	8218
Termination Stiffness	MPa	4834	5081	4922	4656	4415	4409
Modulus of Elasticity	MPa	9013	8990	12465	11048	8791	9577
Phase angle	Degrees	26.1	19.2	23.9	23.7	20.9	47.4

From the results, interpretation of the data gives to the no. of cycle, tensile stress, the modulus of elasticity and stiffness properties of the mixture.

4.4.1.1 *Fatigue Life, Cycles*

The fatigue properties were important in order to have durable pavement. The fatigue life measured from the laboratory experiment was compared between different bitumen contents and grades. The summary of cycles for every samples shows in Table 14.

Table 14 : No of Cycles for each specimens

Bitumen Content (%)	Cycles, N		
	Sample 1	Sample 2	Average
5.05	54250	307490	180870
5.55	307490	230070	268780
6.05	36190	24920	30555
6.3	105440	40730	73085
6.8	71050	49500	60275
7.3	311130	8330	159730

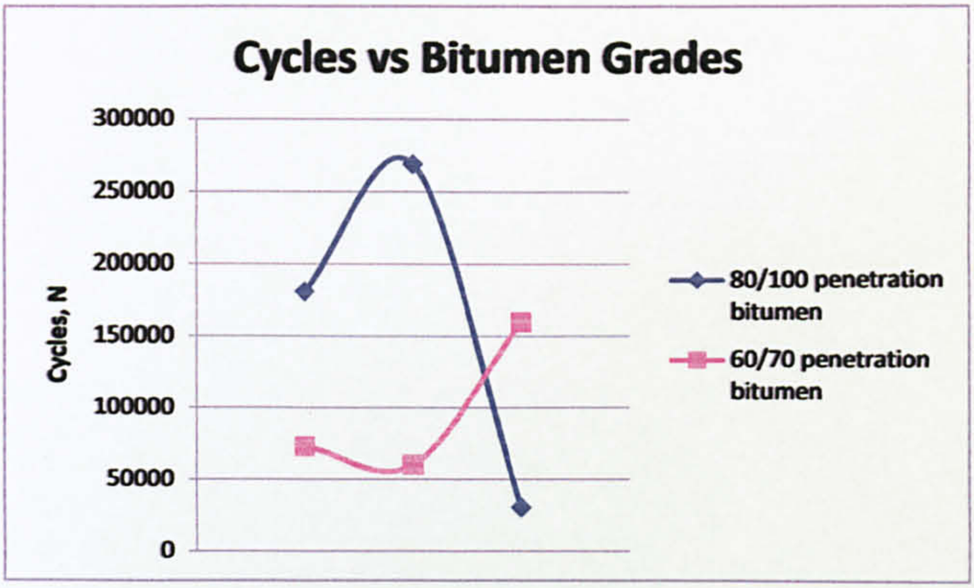

Figure 12 : Graph cycles vs. different bitumen grades

Figure 12 shows the 80/100 penetration bitumen give more higher cycles compare to 60/70 penetration bitumen. The OBC for AC mixture give the higher no of cycles while the OBC for HRA mixture gives the lowest data. However, the lowest cycles comes from 6.05% of 80/100 penetration bitumen.

4.4.1.2 *Maximum Tensile Stress*

For the experiment, the sinusoidal strain control mode has been used. The maximum tensile stress was measured by comparing with different bitumen contents and grades. The summary of maximum tensile stress for every samples shows in Table 15.

Table 15 : Maximum Tensile Stress for each specimens

Bitumen Content (%)	Maximum Tensile Stress (kPa)		
	Sample 1	Sample 2	Average
5.05	375	697	536
5.55	586	634	610
6.05	617	590	603.5
6.3	490	835	662.5
6.8	1068	1118	1093
7.3	815	908	861.5

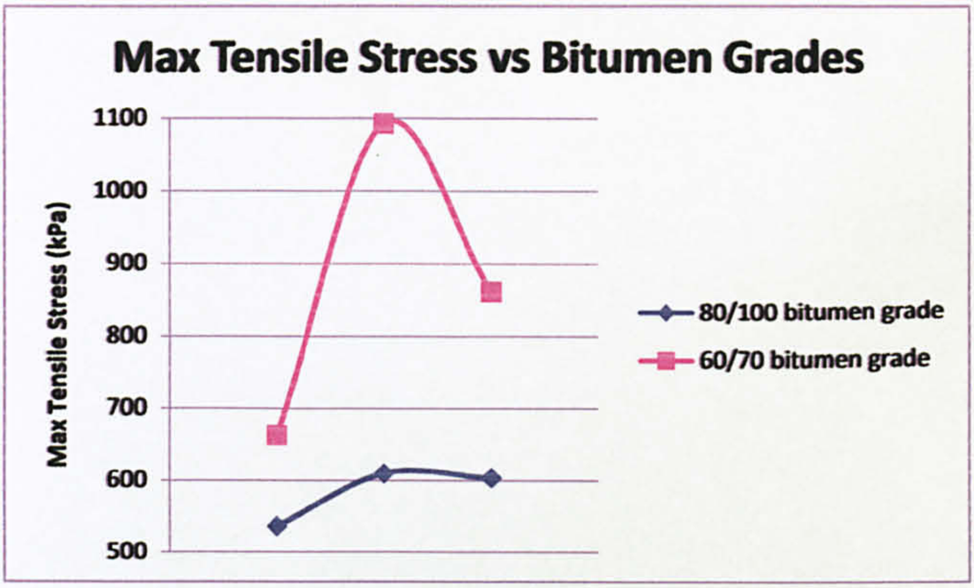

Figure 13 : Maximum Tensile Stress vs. Different bitumen grades

Figure 13 shows that the 60/70 bitumen grades indicate more higher tensile stress compared with 80/700 bitumen grade. For both mixtures whether AC or HRA, it shows that the OBC give the higher tensile stress.

4.4.1.3 *Modulus of Elasticity*

An elastic modulus, or modulus of elasticity, is the mathematical description of an object or substance's tendency to be deformed elastically when a force is applied to it. From Figure 14, it is shows that all lines are almost a straight line and parallel to each other. The lines also indicate incline negatively that give negative slope for every line.

From interpretation of data, it is demonstrate that 60/70 bitumen for HRA have higher modulus value compare to 80/100 bitumen for AC mixture. For both OBC also indicate that the modulus values are higher compare to +/- 0.5 OBC. The maximum stiffness of OBC value may due to the absolute amount of bitumen that gave the higher performance.

However, by ranked the slope for each bitumen content as shown in Table 16, it is indicate that the 60/70 pen bitumen grade for OBC give the faster rate of fatigue life. Although the OBC give high stiffness, the fatigue behaviour may occurs faster compare to other bitumen grades.

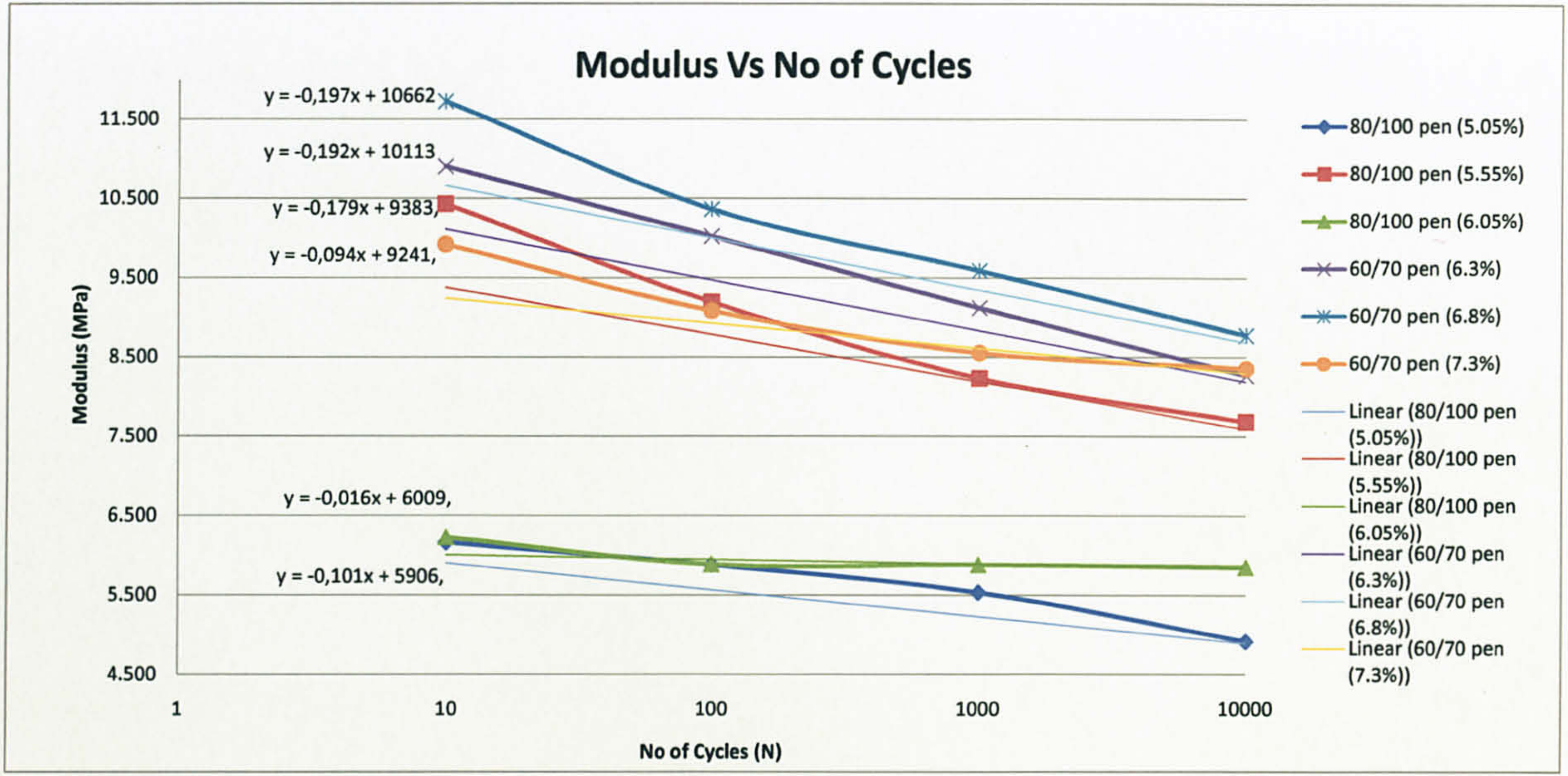

Figure 14 : Modulus vs No of Cycles

Table 16 : Summary of Linear Equation for Modulus vs Cycles

Bitumen Grade	Bitumen Content (%)	Linear Equation	Slope, -m	Overall Ranked Slope	Ranked Slope by Bitumen Grade
80/100	5.05	y = -0.101x + 5906	0.101	4	2
	5.55	y = -0.179x + 9383	0.179	3	1
	6.05	y = -0.016x + 6009	0.016	6	3
60/70	6.3	y = -0.192x + 10113	0.192	2	2
	6.8	y = -0.197x + 10662	0.197	1	1
	7.3	y = -0.094x + 9241	0.094	5	3

4.4.1.4 *Bituminous Mixture Stiffness*

Every initial stiffness value is important to determine the eliminate stiffness as half of the initial stiffness for beam fatigue test. The initial stiffness was measured at 50 cycles and every specimen may give different value. The summary of initial stiffness for every samples shows in Table 17.

Table 17 : Initial Stiffness for every specimens

Bitumen Content (%)	Initial Stiffness (MPa)		
	Sample 1	Sample 2	Average
5.05	5971	5444	5707.5
5.55	11741	5896	8818.5
6.05	5439	5565	5502
6.3	9668	9344	9506
6.8	9844	9311	9577.5
7.3	8830	8819	8824.5

Figure 15 and 16 shows the initial stiffness for different bitumen content respect to each bituminous mixture. The graph indicate that the OBC value gives the higher initial stiffness whether AC or HRA mixture.

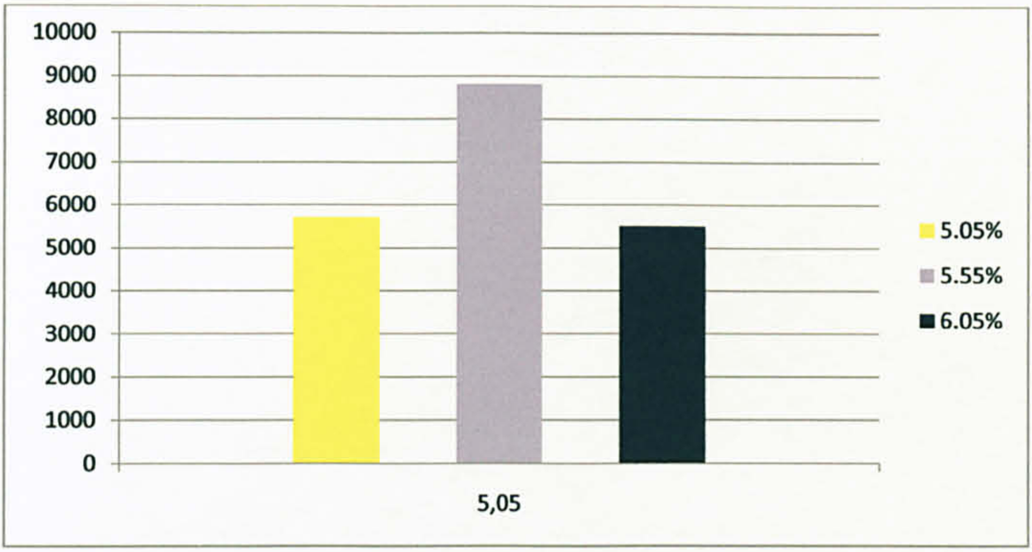

Figure 15 : Initial stiffness vs. 80/100 penetration bitumen

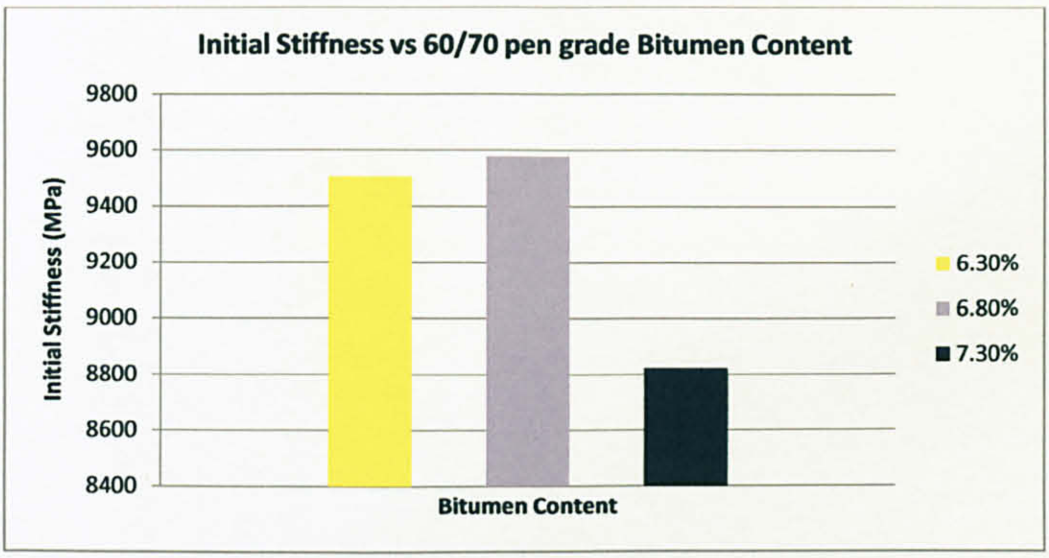

Figure 16 : Initial stiffness vs. 60/70 penetration bitumen

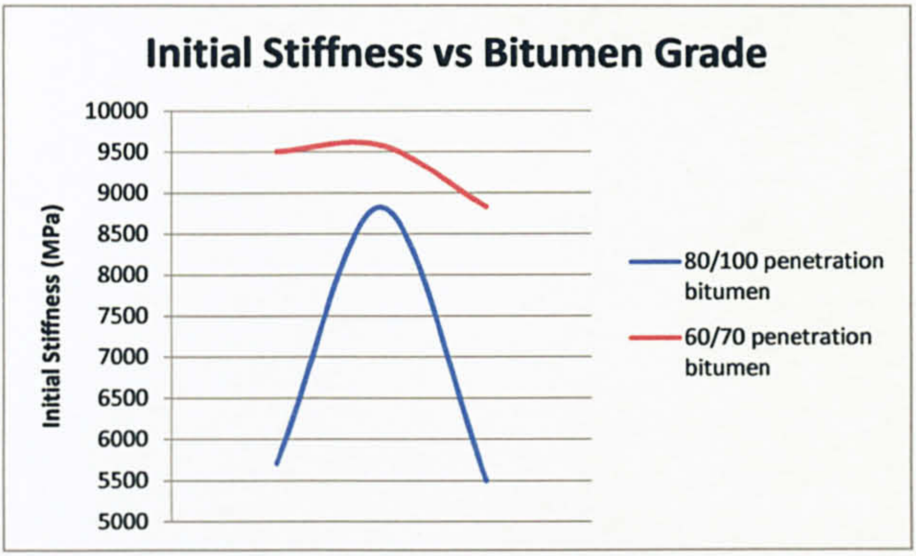

Figure 17 : Initial Stiffness vs. Bitumen grades

Figure 17 show the comparison between 80/100 and 60/70 penetration bitumen for initial stiffness value. The 60/70 penetration bitumen shown that it give higher stiffness compare to 80/100 penetration bitumen.

4.5 Discussion

4.5.1 Material Properties

All the material properties used for the experiment need to be lies within the allowable range setup by JKR. By following JKR requirement, the bituminous design may demonstrate the actual design on site. This is important to make sure all the data were significant to the real pavement later on.

From the bitumen properties, it shows that the 60/70 bitumen is more stiff compare to 80/100. Due to this statement, 60/70 bitumen grade may appropriate use with aggregate gap gradation. The stiffness also makes the ductility properties for 60/70 penetration lower compare to 80/70 penetration. However, the ductility property is still in allowable range. Bitumen grade 60/70 have high softening point compare to 80/100 penetration. With low softening point, the pavement may be occur rutting problem compare to high softening point due to low stiffness of pavement.

4.5.2 Marshall Mix Design

For Marshall Mix design, the AC and HRA mix will be used. The AC bituminous would comprise well graded aggregate and HRA with gap graded aggregate distribution. As the result shows in Table 8, the amount of bitumen needed for HRA mixture is higher compare to AC mixture because the HRA have more fine aggregate compare to AC mixture. The more area needed to be coated due to more fine aggregate that have grater surface area.

In term of construction cost, HRA mixture would be more costly compare to AC mixture due to high bitumen price in the market and amount needed. However, the other engineering aspect needed to be analysing before laying the pavement in order to have pavement that cost effective.

The strength of the AC mixture comes from the interlocking affect of the aggregate and for HRA mixture strength comes from the stiffness of the mortar. The OBC that determine in the design is important to demonstrate its properties to the actual pavement.

4.5.3 Beam Fatigue Test

AC mixture demonstrates the longer fatigue life compare to HRA mix. The longer cycle explain the longer fatigue life of the pavement. The aggregate gradation for AC mixture may affect the cycle's results. With a longer fatigue life means the pavement can sustain in longer term duration or number of vehicle passing by. The pavement may have higher PSI value and take longer duration before the pavement rehabilitation.

For tensile stress, modulus of elasticity, and stiffness properties, its shows that 60/70 penetration bitumen grade have the higher value compare to 80/100 penetration bitumen grade. Due to the stiffness of the mortar, the initial stiffness of 60/70 penetration bitumen grade gives a high result. The HRA mixture can sustain more traffic load compare to AC mixture because of the stiffness properties.

The maximum tensile stress value for HRA indicate the maximum force that being applied in tension higher compare to AC mixture. The tensile stress applied in the test indicated the maximum stress that the specimen can sustain before rupture. With higher tensile strength the pavement may rarely maintenance due enable to sustain from deformation.

From the Figure 13 it is shows that the 60/70 penetration bitumen have the higher modulus of elasticity. The value of modulus of elasticity is important becau it is decide on how the material can elongate, after a particular stage, before it might break and never return to its original shape. Thus modulus of elasticity always seems to be important parameter in designing the pavement. The problem such as rutting may lower for HRA mixture compare to AC mixture due to high modulus of elasticity value.

4.5.4 Indirect Tensile Stiffness Modulus (ITSM)

From the Figure 11 interpretation, the 60/70 pen bitumen grade give higher stiffness modulus value compare to 80/100 pen bitumen grade. The effect of stiffness of mortar may influence more compare to the interlocking effect of aggregate.

In that case, the performance of HRA in term of stiffness pavement is better compare to AC. Therefore, the resistance potential in HRA pavement to prevent deformation from occur is more better comparing to AC mixture.

CHAPTER 5

ECONOMICAL BENEFITS

5.1 Cost Analysis

The cost analysis is taking into consideration of Coarse Aggregate, Fine Aggregate, and Bitumen Grade. The calculation is based on the calculation of pavement cost by the asphalt Institute.

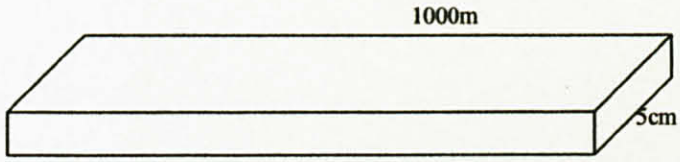

Figure 18 : Cross section of a pavement

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 18. The following information was obtained from the recent market price.

Coarse Aggregate (granite), RM250 per ton

Fine Aggregate, RM100 per ton

Bitumen 80/100 penetration grade, RM 1850 per ton

Bitumen 60/70 penetration grade, RM 2500 per ton

By multiplying each items with their corresponding pay units from Table 1-1 in the guideline (Refer Appendix E)

Asphaltic Concrete Mixture (Well graded aggregate gradation with 80/100 bitumen grade)

CA:	RM250 per ton x 0.0496 x 1.97 in.	= RM24.49 per sq yd
FA:	RM100 per ton x 0.0495 x 1.97 in.	= RM09.75 per sq yd
Bitumen 80/100:	RM1850 per ton x 0.0029 x 1.97 in.	= RM10.57 per sq yd
Total:		= RM44.81 per sq yd
Converting to m^2:	RM 44.81 per sq yd x 0.83613	= RM 37.47 per m^2

Hot Rolled Asphalt Mixture (Gap graded aggregate gradation with 60/70 bitumen grade)

CA:	RM250 per ton x 0.05 x 1.97 in.	= RM24.63 per sq yd
FA:	RM100 per ton x 0.05 x 1.97 in.	= RM09.85 per sq yd
Bitumen 80/100:	RM2500 per ton x 0.00365 x 1.97 in.	= RM17.98 per sq yd
Total:		= RM52.45 per sq yd
Converting to m^2:	RM 52.45 per sq yd x 0.83613	= RM 43.86 per m^2

Table 18 : Cost summary of AC and HRA mixture

Bituminous Mixture	Cost (RM per m^2)	Total cost for 1000m (RM/ 1m width)
Asphaltic Concrete	37.47	37470
Hot Rolled Asphalt	43.86	43860

Based on the cost summary in Table 18, it is clearly shown that mixture with 80/100 bitumen (AC mixture) will provides the lowest cost. The major cost of the material comes from the CA although the bitumen indicated the higher price per ton. In the market, the cost of 60/70 penetration bitumen is higher than 80/100 penetration bitumen. However, by provides additional money into the project, better engineering properties can be achieved. The maintenance for the HRA mixture may be lesser compare to AC mixture due to tensile and fatigue properties.

CHAPTER 6
CONCLUSION AND RECOMMENDATION

6.1 Conclusion

This project deals with two type of bitumen grades which are 60/70 penetration bitumen and 80/100 penetration bitumen. The main objective of the project is to obtain the effect of different bitumen grades on Hot Rolled Asphalt (HRA) and Asphaltic Concrete (AC) corresponding with tensile and fatigue behaviours.

From the Beam Fatigue testing and ITSM, it is shown that the HRA mixture that used 60/70 pen grade bitumen demonstrate higher value of Modulus compare to AC mixture. The more stiffness bitumen that used in HRA mixture may affect the Modulus value.

Therefore, the influence of bitumen stiffness is more compare to the interlocking effect of aggregate to perform a better pavement in term of tensile and fatigue properties. Although the bitumen content for HRA mixture is more compare to AC mixture, the modulus value is higher for mixture with 60/70 pen grade bitumen.

Bituminous that higher stiffness may give better performance of pavement. The more stiffness may give better resistance to the deformation failure of pavement. With high performance of bituminous mixture, the maintenance cost may be reduced compare to the pavement that need frequently be repaired.

At last, or tensile and fatigue behaviours or properties, it is shows that 60/70 penetration bitumen give high value of tensile while 80/100 penetration bitumen give longer cycles for fatigue life. It is shows that with different bitumen grade it will affect the tensile and fatigue properties. However, in term of cost the HRA mixture would more costly due to more bitumen content needed.

6.2 Recommendation

In order to more critical analysis and significant result, some of the recommendation actions or steps may be use.

1. The Superpave bituminous mix may be used that utilize the Gyratory Compaction Machine. The result may give a better interpretation due to better compaction method.
2. Instead of different bitumen grades, some polymer may be added to check the effect to the tensile and fatigue properties of the mixture.
3. For Beam Fatigue Test, varies some of the parameter such the temperature, frequency, type of mode control and the poison ratio value.

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APPENDICES

APPENDIX A

AGGREGATE DISTRIBUTION

AGGREGATE ALLOWABLE DISTRIBUTION

B.S. Sieve Size (mm)	% Passing by Weight
37.5	100
28.000	100
20.000	100
14.000	80-95
10.000	68-90
5.000	52-72
3.350	45-62
1.180	30-45
0.425	17-30
0.150	7-16
0.075	4-10

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

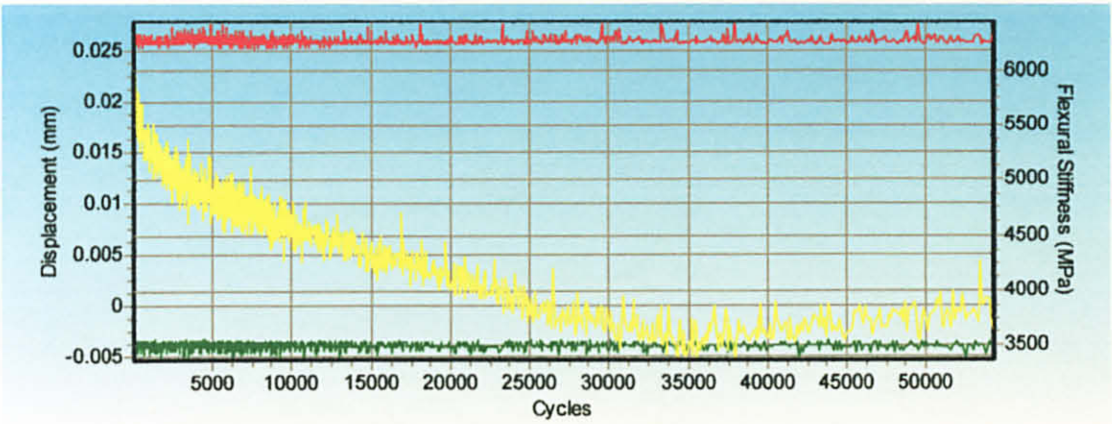
B.S. Sieve Size (mm)	Coarse Agg. (%)	Fine Agg. (%)	Filler (%)	Total (%)
20.000	35.00	55.00	10.00	100.00
14.000	31.44	55.00	10.00	96.44
10.000	5.79	55.00	10.00	70.79
6.300	0.36	55.00	10.00	65.36
5.000	0.17	54.63	10.00	64.80
2.360	0.09	53.83	10.00	63.92
0.600	0.00	51.60	10.00	61.60
0.300	0.00	21.88	10.00	31.88
0.212	0.00	13.16	10.00	23.16
0.125	0.00	0.00	9.99	9.99
0.090	0.00	0.00	9.96	9.96
0.075	0.00	0.81	9.85	10.66
0.630	0.00	0.00	9.42	9.42
0.045	0.00	0.00	0.85	0.85

Source: The Properties of Performance of Polymer Fiber Reinforced HRA

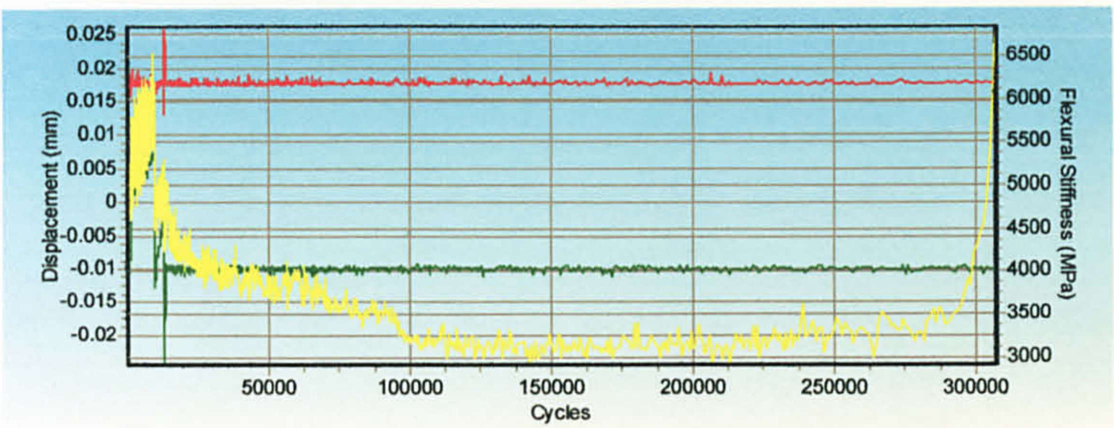
APPENDIX B

BEAM FATIGUE RESULT

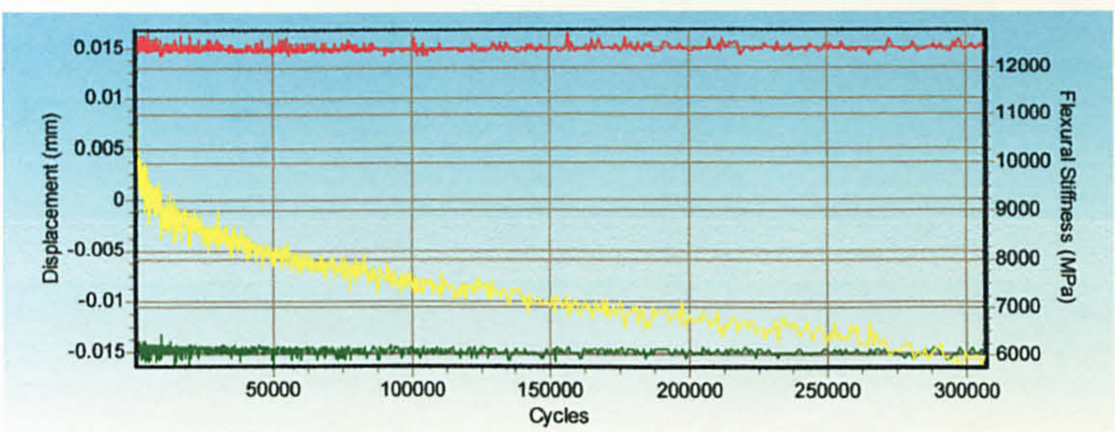
<u>BEAM FATIGUE TEST RESULT</u>



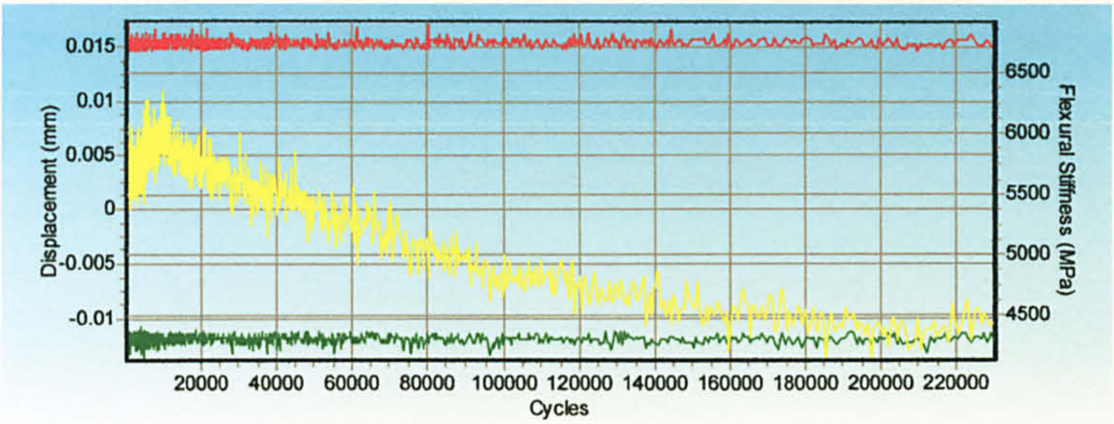
Asphaltic Concrete 5.05% of bitumen content specimen 1



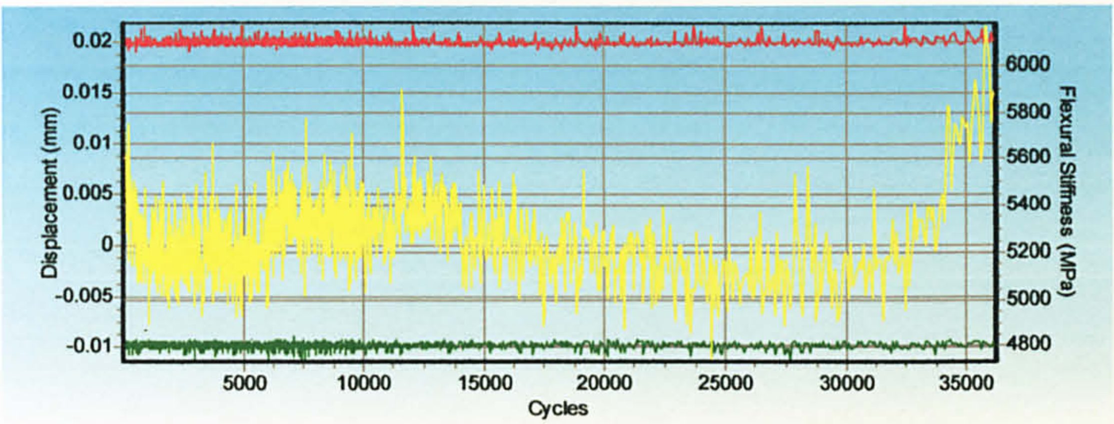
Asphaltic Concrete 5.05% of bitumen content specimen 2



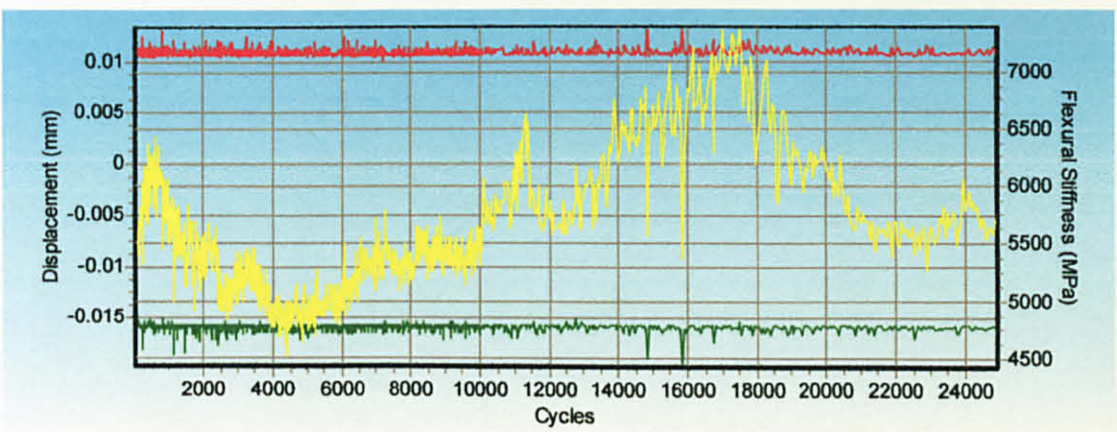
Asphaltic Concrete 5.55% of bitumen content specimen 1



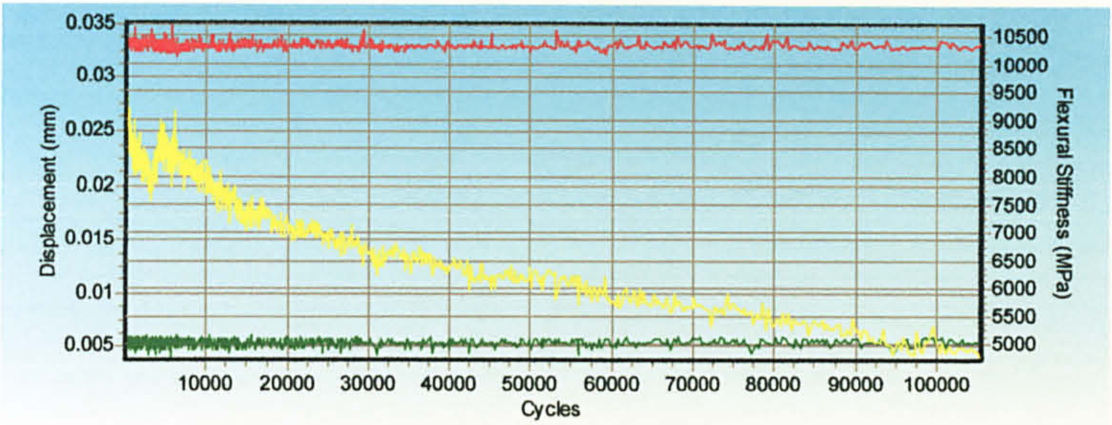
Asphaltic Concrete 5.55% of bitumen content specimen 2



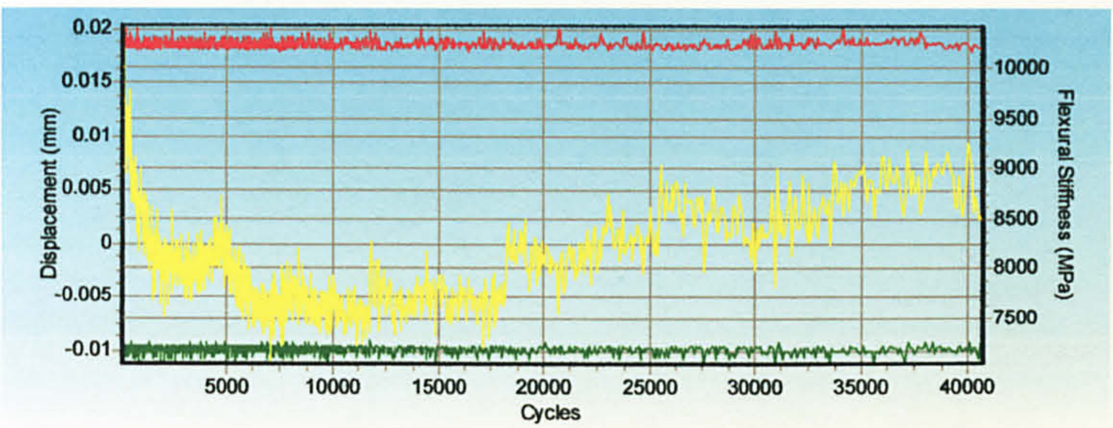
Asphaltic Concrete 6.05% of bitumen content specimen 1



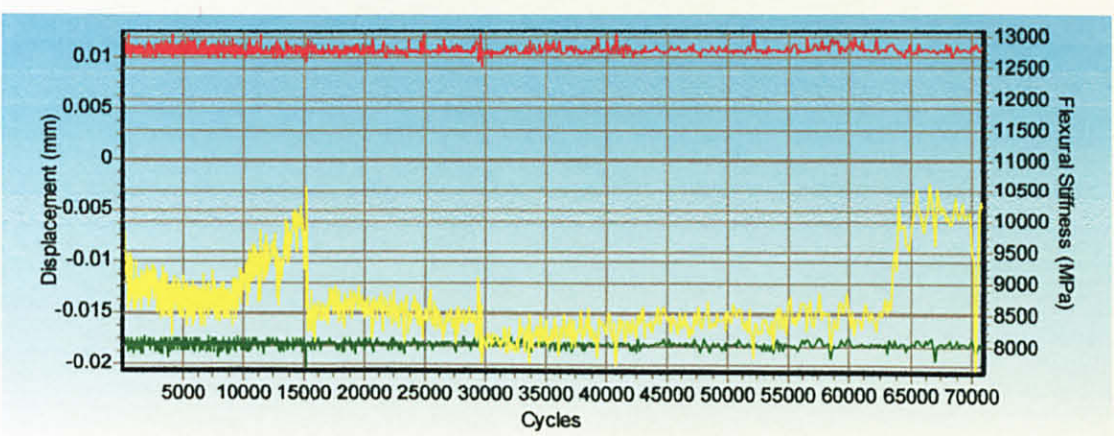
Asphaltic Concrete 6.05% of bitumen content specimen 2



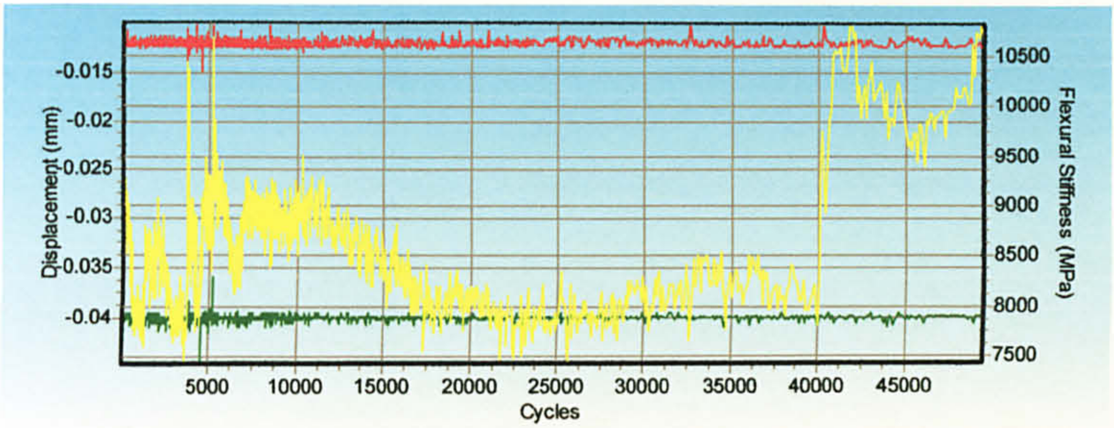
Hot Rolled Asphalt 6.30% of bitumen content specimen 1



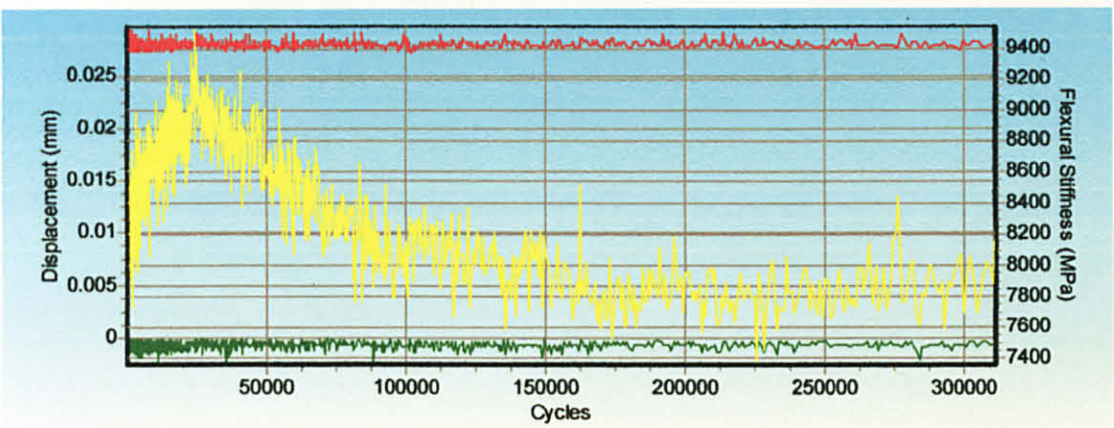
Hot Rolled Asphalt 6.30% of bitumen content specimen 2



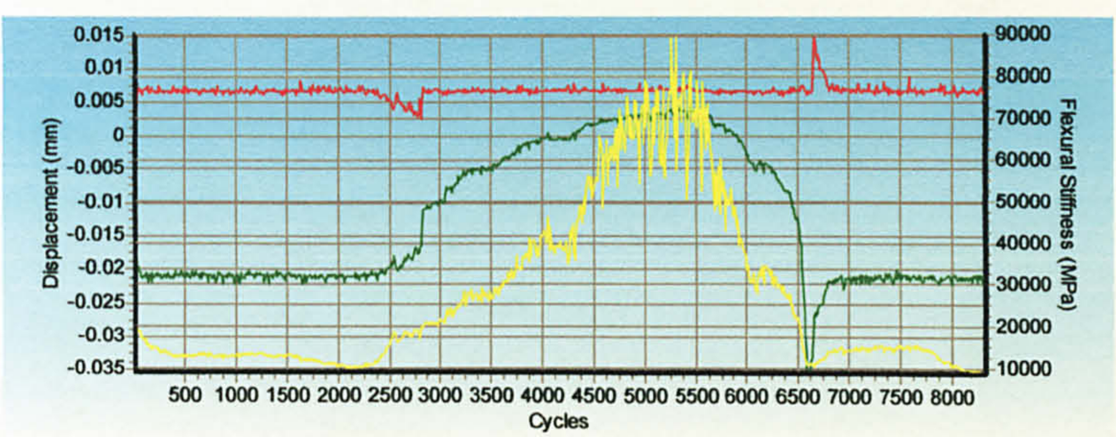
Hot Rolled Asphalt 6.80% of bitumen content specimen 1



Hot Rolled Asphalt 6.80% of bitumen content specimen 2



Hot Rolled Asphalt 7.30% of bitumen content specimen 1



Hot Rolled Asphalt 7.30% of bitumen content specimen 2

AC mixture with 80/100 pen grade bitumen

Bitumen Content (5.05%)

Cycles	Modulus (MPa) Specimen 1	Modulus (MPa) Specimen 2	Average Modulus (Mpa)
10	6797.459	5530.657	6164.058
100	6176.542	5586.008	5881.275
1000	5772.469	5296.908	5534.689
10000	4830.746	5008.896	4919.821

Bitumen Content (5.55%)

Cycles	Modulus (MPa) Specimen 1	Modulus (MPa) Specimen 2	Average Modulus (Mpa)
10	13481.962	7378.392	10430.177
100	11829.214	6554.028	9191.621
1000	10588.958	5874.009	8231.484
10000	9218.199	6153.967	7686.083

Bitumen Content (6.05%)

Cycles	Modulus (MPa) Specimen 1	Modulus (MPa) Specimen 2	Average Modulus (Mpa)
10	6248.278	6209.176	6228.727
100	5808.721	5965.285	5887.003
1000	5547.622	6213.692	5880.657
10000	5691.373	6013.392	5852.382

HRA mixture with 60/70 pen grade bitumen

Bitumen Content (6.3%)

Cycles	Modulus (MPa) Specimen 1	Modulus (MPa) Specimen 2	Average Modulus (Mpa)
10.000	11419.531	10384.709	10902.120
100.000	10023.268	10824.393	10423.831
1000.000	9180.008	9060.077	9120.042
10000.000	8382.933	8159.090	8271.012

Bitumen Content (6.8%)

Cycles	Modulus (MPa) Specimen 1	Modulus (MPa) Specimen 2	Average Modulus (Mpa)
10.000	13850.063	9596.865	11723.464
100.000	10141.063	9617.219	9879.141
1000.000	9592.674	8520.965	9056.820
10000.000	9588.505	9029.851	9309.178

Bitumen Content (7.3%)

Cycles	Modulus (MPa) Specimen 1	Modulus (MPa) Specimen 2	Average Modulus (Mpa)
10.000	9921.974	9921.974	9921.974
100.000	9083.888	9083.888	9083.888
1000.000	8552.369	8552.369	8552.369
10000.000	9103.047	9103.047	9103.047

APPENDIX C

CALCULATION FOR BEAM FATIGUE SPECIMENS

Calculation for density based on Marshall specimens

Bitumen Content (%)	Weight(g)		Volume (cm^3)	Density	Average Density
	Air	Water			
6.3	1241.5	624	617.5	2.0105263	2.0
	1259.5	618.5	641	1.9648986	
	1269.5	639	630.5	2.0134814	
6.8	1229.5	614	615.5	1.997563	2.0
	1222.5	607	615.5	1.9861901	
	1275	640	635	2.007874	
7.3	1242	629	613	2.0261011	2.0
	1260.5	635.5	625	2.0168	
	1265.5	639.5	626	2.0215655	
5.05	1267	607	660	1.919697	1.9
	1283	609	674	1.9035608	
	1267	607.5	659.5	1.9211524	
5.55	1262	587.5	674.5	1.8710156	1.9
	1256	600	656	1.9146341	
	1245	581	664	1.875	
6.05	1244	582	662	1.8791541	1.9
	1224	584	640	1.9125	
	1210.5	585	625.5	1.9352518	

Summary of Beam Fatigue specimen material

Bituminous Mixture	Bitumen Content	Amount (g)			
		CA	FA	Filler	Bitumen
AC	5.05	3788.5	4510.1	721.6	479.8
	5.55	3978.6	4736.4	757.8	527.3
	6.05	3958.6	4712.6	754.0	574.8
HRA	6.30	3279.5	5153.5	937.0	630.0
	6.80	3262.0	5126.0	932.0	680.0
	7.30	3244.5	5098.5	927.0	730.0

Calculation for density based on Marshall specimens

Bitumen Content (%)	Weight(g)		Volume (cm^3)	Density	Average Density
	Air	Water			
	1241.5	624	617.5	2.0105263	2.0
	1259.5	618.5	641	1.9648986	
6.3	1269.5	639	630.5	2.0134814	
	1229.5	614	615.5	1.997563	2.0
	1222.5	607	615.5	1.9861901	
6.8	1275	640	635	2.007874	
	1242	629	613	2.0261011	2.0
	1260.5	635.5	625	2.0168	
7.3	1265.5	639.5	626	2.0215655	
	1267	607	660	1.919697	1.9
	1283	609	674	1.9035608	
5.05	1267	607.5	659.5	1.9211524	
	1262	587.5	674.5	1.8710156	1.9
	1256	600	656	1.9146341	
5.55	1245	581	664	1.875	
	1244	582	662	1.8791541	1.9
	1224	584	640	1.9125	
6.05	1210.5	585	625.5	1.9352518	

Summary of Beam Fatigue specimen material

Bituminous Mixture	Bitumen Content	Amount (g)			
		CA	FA	Filler	Bitumen
AC	5.05	3788.5	4510.1	721.6	479.8
	5.55	3978.6	4736.4	757.8	527.3
	6.05	3958.6	4712.6	754.0	574.8
HRA	6.30	3279.5	5153.5	937.0	630.0
	6.80	3262.0	5126.0	932.0	680.0
	7.30	3244.5	5098.5	927.0	730.0

HRA mixture with 60/70 pen grade bitumen

Bitumen content = 6.3%

B.S. Sieve Size (mm)	% Passing by Weight	% Retained on Sieve	Required Weight (g)
20.000	100.00	0.00	0.00
14.000	96.44	3.56	333.57
10.000	70.79	25.65	2403.41
6.300	65.36	5.43	508.79
5.000	64.80	0.56	52.47
2.360	63.92	0.88	82.46
0.600	61.60	2.32	217.38
0.300	31.88	29.72	2784.76
0.212	23.16	8.72	817.06
0.125	11.00	12.16	1139.39
0.075	10.00	1.00	93.70
Filler	0.00	10.00	937.00
Total		100.00	9370.00

Bitumen content = 6.3%

B.S. Sieve Size (mm)	% Passing by Weight	% Retained on Sieve	Required Weight (g)
20.000	100.00	0.00	0.00
14.000	96.44	3.56	331.79
10.000	70.79	25.65	2390.58
6.300	65.36	5.43	506.08
5.000	64.80	0.56	52.19
2.360	63.92	0.88	82.02
0.600	61.60	2.32	216.22
0.300	31.88	29.72	2769.90
0.212	23.16	8.72	812.70
0.125	11.00	12.16	1133.31
0.075	10.00	1.00	93.20
Filler	0.00	10.00	932.00
Total		100.00	9320.00

Bitumen content = 7.3%

B.S. Sieve Size (mm)	% Passing by Weight	% Retained on Sieve	Required Weight (g)
20.000	100.00	0.00	0.00
14.000	96.44	3.56	330.01
10.000	70.79	25.65	2377.76
6.300	65.36	5.43	503.36
5.000	64.80	0.56	51.91
2.360	63.92	0.88	81.58
0.600	61.60	2.32	215.06
0.300	31.88	29.72	2755.04
0.212	23.16	8.72	808.34
0.125	11.00	12.16	1127.23
0.075	10.00	1.00	92.70
Filler	0.00	10.00	927.00
Total		100.00	9270.00

AC mixture with 81/100 pen grade bitumen

Bitumen content = 5.05%

B.S. Sieve Size (mm)	% Passing by Weight	% Retained on Sieve	Required Weight (g)
28	100	0	0
20	100	0	0
14	95	5	451.0125
10	90	5	451.0125
5	72	18	1623.645
3.35	58	14	1262.835
1.18	35	23	2074.6575
0.425	20	15	1353.0375
0.15	10	10	902.025
0.075	8	2	180.405
Filler	0	8	721.62
Total		100	9020.25

Bitumen content = 5.55%

B.S. Sieve Size (mm)	% Passing by Weight	% Retained on Sieve	Required Weight (g)
28	100	0	0
20	100	0	0
14	95	5	473.6375
10	90	5	473.6375
5	72	18	1705.095
3.35	58	14	1326.185
1.18	35	23	2178.7325
0.425	20	15	1420.9125
0.15	10	10	947.275
0.075	8	2	189.455
Filler	0	8	757.82
Total		100	9472.75

Bitumen content = 6.05%

B.S. Sieve Size (mm)	% Passing by Weight	% Retained on Sieve	Required Weight (g)
28	100	0	0
20	100	0	0
14	95	5	471.2625
10	90	5	471.2625
5	72	18	1696.545
3.35	58	14	1319.535
1.18	35	23	2167.8075
0.425	20	15	1413.7875
0.15	10	10	942.525
0.075	8	2	188.505
Filler	0	8	754.02
Total		100	9425.25

APPENDIX D

GANTT CHART

FYP 1 Gantt Chart

No	DETAILS/WEEK	1	2	3	4	5	6	7	8	9	Mid- Semester Break	10	11	12	13	14
1	Selection of project topic	■	■								■					
2	Preliminary research work		■	■	■						■					
3	IEM Talk				■						■					
4	IRC Workshop & Technical Writing Workshop					■					■					
5	Technical Writing Workshop (Part II)						■				■					
6	Submission of journal papers						■				■					
7	Project Work:										■					
	i: Review on literature					■	■	■	■		■					
	ii: Seach for Codes and Standard Procedure						■	■	■		■					
	iii: Calculation for aggregate gradation							■	■	■	■	■	■	■		
	iv: Calculation for Marshall Mix Design							■	■	■	■	■	■	■		
8	Submission of Progress Report							■			■					
9	HSE Talk								■		■					
10	Referencing Workshop									■	■					
11	Submission of Interim Report Final Draft										■				■	
12	Oral Presentation										■					■

FYP II Gantt Chart

No	DETAILS/WEEK	1	2	3	4	5	6	7	Mid- Semester Break	8	9	10	11	12	13	14	15
1	Materials preparation																
2	Marshall Mixing for cylindrical specimens																
3	Calculation for Beam Fatigue specimens																
4	Preparation of Beam Fatigue specimens																
5	Testing for Beam Fatigue																
6	Testing for ITSM																
7	Data Analysis																
8	Submission of Progress Report																
9	Poster Exhibition																
10	Preparation and submission of dissertation																
11	Oral Presentation																
12	Hard bound of dissertation preparation and submission																

APPENDIX E

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

JADUAL 2 (Samb.)- HARGA UNIT PURATA BAGI BITUMEN, MINYAK BAHAN API DAN DIESEL
TABLE 2 (Cont'd)- Average Unit Prices for Bitumen, Fuel Oil and Diesel

Perkara *Item*	**Tempoh** *Period*		**Semenanjung Malaysia** *Peninsular Malaysia*	
(2) Minyak Gas Automotif *Automotive Gas Oil*			**RM Seliter** *RM Per Litre*	
			Runcit* *Retail*	**Sebenar** *Actual*
Diesel *Diesel*	2007	Jan.	1.581	1.871
		Feb.	1.581	1.962
		Mac	1.581	2.030
		Apr.	1.581	2.155
		Mei	1.581	2.168
		Jun	1.581	2.185
		Jul.	1.581	2.275
		Ogo.	1.581	2.233
		Sep.	1.581	2.398
		Okt.	1.581	2.444
		Nov.	1.581	2.678
		Dis.	1.581	2.658
	2008	Jan.	1.581	2.602
		Feb.	1.581	2.651
		Mac	1.581	2.951
		Apr.	1.581	3.176
		Mei	1.581	3.610
		Jun	2.581	3.848
		Jul.	2.581	3.866
		Ogo.		
		Sep.		
		Okt.		
		Nov.		
		Dis.		

Harga diesel diperoleh daripada Kementerian Perdagangan Dalam Negeri dan Hal Ehwal Pengguna dan harga adalah ex-Kuala Lumpur.
Diesel price is obtained from Ministry of Domestic Trade and Consumer Affairs and price is at ex-Kuala Lumpur.
*** Harga runcit ialah harga selepas ditolak subsidi kerajaan.**
Retail price is the price less government subsidy.