Recycling Building Demolition Waste in

Hot-Mix Asphaltic Concrete

By

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CERTIFICATION OF APPROVAL

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Approved by,

____

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ABSTRACT

Solid waste can be defined as the useless and unwanted products in the solid state derived from the activities of and discarded by society [1]. Specific definition from Ministry of Housing and Local Government that control solid waste management in Malaysia say that solid waste can be define as any scrap material or other unwanted surplus substance or rejected products arising from the application of any process, any substance required to be disposed of as being broken, worn out, contaminated or otherwise spoiled; or any other material that is required by the authority to be disposed of [2].

Solid waste is one of the three major environmental problems in Malaysia. It plays a significant role in the ability of Nature to sustain life within its capacity. Currently, over 23,000 tonnes of waste is produced each day in Malaysia. However, this amount is expected to rise to 30,000 tonnes by the year 2020. The amount of waste generated continues to increase due to the increasing population and development, and only less than 5% of the waste is being recycled [1].

Apart of solid waste that derived from household and commercial activity, solid waste from construction also bring significant value to the environmental problem. Research that had been done by Asian Institute of Technology School of Environment, Resources and Development shows that 28.34% (including industrial waste) come from construction and demolition (C & D) waste which produce 1.55 Million Tons per year [4].

At the same time, the sources of natural aggregates are depleted and there is an increasing demand because of the increased construction and maintenance activity from time to time. At that point, this project will consist of further research on recycling the aggregate that been obtain from building demolition waste for asphalt concrete. Tests will be conducted to evaluate the performance of asphalt concrete made with recycled aggregate to know whether it met all the requirements of local specifications or not.

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CHAPTER 1

INTRODUCTION

1.0 INTRODUCTION

1.1 Background of Study

Since early 16th century in the colonization of British and Dutch, only a few building was built in Malaysia. In early 20th century, as the economic condition improved, building construction started to grow all around the country. After 40-50 years, many of these buildings require demolition for reconstruction or major renovations. The demolition of these buildings creates large amounts of debris and waste known as construction and demolition (C & D) waste. Most C&D waste goes into landfills, increasing the burden on landfill loading and operation. As the sources of natural aggregates are depleted and there is an increasing demand because of the increased construction and maintenance activity from time to time, this project will consist of further research on recycling the aggregate that been obtain from building demolition waste for asphalt concrete. The output of this study can be used to evaluate the operation and performance of asphalt concrete made with recycled aggregate.

Figure 1.1 : Building Demolition Activity

1.2 Problem Statements

1. The past decade of rapid economic growth and industrialization has caused serious environmental challenges in Malaysia.
2. Due to growing population and increasing consumption, Malaysia generates waste at 23,000 tons per day [1].
3. Solid waste is one of the three major environmental problems in Malaysia. And almost 30% of the solid waste came from building construction and demolition (C&D) [3].
4. Most C&D waste goes into landfills, increasing the burden on landfill loading and operation.
5. A proper research on recycle or reuse of C&D waste should be done to sustain the world from solid waste.
6. Sources of natural aggregates are depleted and there is an increasing demand for new development. It means, Recycling Building Demolition Waste in Hot-Mix Asphaltic Concrete will bring benefit to the environment and at the same time, it provide alternative for aggregate in asphaltic concrete.

1.3 Objectives

1. To improve environment condition by recycle and reuse building construction and demolition, one of the significant solid waste.
2. To provide alternative for aggregate in asphaltic concrete.
3. To further investigate the performance of asphalt concrete made with recycled aggregate whether it met all the requirements of local specifications or not.

1.4 Scope of Study

In order to complete this project, several scopes of study and laboratory test had to be done. The major scopes are as follows:

1. To get information on type of building demolition that suitable to be recycled or reused.

- There will be a research towards the current building demolition type and its composition.

2. To study on default ingredient of hot mix asphaltic concrete and the mechanism
   - It will be some research of current aggregate used.
   - The research of building demolition as the alternative of aggregate will be done

3. To test the quality and performance of recycled building demolition as aggregate in hot mix asphaltic concrete.
   - It will be some laboratory test to be conducted throughout the project such as The Marshall Test, Immersion Compression Test, Loss of Stability Test and the Wheel Track Test
   - The laboratory test is to evaluate the asphalt concrete made with recycled aggregate

1.5 Relevancy of the studies

This study is relevance to the highway construction industries construction and demolition recycling industry. The joint venture is significant for them to add the environment friendly element to replace natural coarse aggregate with recycling building demolition. By the result of this research, recycling building demolition can solve the depleted natural aggregate problem and lead to a better performance of hot mix asphaltic concrete.

1.6 Feasibility of the study

This research is feasible because of the availability of materials of natural aggregate and sample of recycling concrete. The equipments in Universiti Teknologi PETRONAS (UTP) are also significant to carry out this project.

CHAPTER 2

LITERATURE REVIEW

Solid waste is a major sustainability concern and actions are urgently required to develop a thoroughly technical knowledge base for enabling appropriate use of material, rather than disposing of all the material used in landfill. The government, private sector and researches are struggling to solve this matter. The info of their researches can be referred at Global Environment Centre website and presentation by Department of National Solid Waste Management, Ministry of Housing and Local Government on Solid Waste Management in Malaysia. Construction and demolition waste are most common type of solid waste in Malaysia

Based on research done by Asian Institute of Technology, School of Environment and Development Thailand in their research entitled Report on Reduce, Reuse and Recycle (3r) Practices in Construction and Demolition Waste Management in Asia shows that 65.80% of recycling building demolition in Malaysia consists of concrete and aggregate. It indicates that this project is significant to be conducted in this country [3].

There are a lot of references from textbooks, handbook, and encyclopedia that are dealing with construction demolition waste and specialized topics as well as journals are available in the area of recycle waste in asphalt concrete. Among the reference books that describes about construction waste is edited by Mukesh C.Limbachiya and John J.Robert in Construction Demolition Waste. It presented 40 papers regarding International Conference to explore waste minimization practice that been held by the Concrete and Masonry Research Group. All of them give related information about recycling building demolition method [4].

The specific journals that describe Recycling Building Demolition Waste in Hot-Mix Asphaltic Concrete in Kuwait by Ahmad H.Aljassar, Khalifa Bader Al-Fadala and Mohammed A.Ali also bring a holistic view towards this project including laboratory test that should be conducted which are The Marshall Test, Immersion Compression Test, Loss of Stability Test and the Wheel Track Test and the result of test done in Kuwait had been attached [5].

The journal written Marios N. Soutsos, Kangkang Tang, Stephen G. Millard has described the concrete building blocks made with recycled demolition aggregate especially on the case study done at United Kingdom [6]. These journals give clear overview on what kind of materials is used and what experimental methods should be taken. It provides few manipulated variables for this experiment to know the optimum quality of recycle aggregate. It consists of the study on RCA (recycle concrete aggregate) and RMA (recycle masonry aggregate).

Journal entitles Evaluation of Building Material Recycling on HMA permanent Deformation by Shen and Du had done an experiment towards aggregate and bitumen [7]. There are 2 types of aggregate which are River Crushed Stone (RCS) and Reclaimed Building Material (RBM) and 2 type of asphalt cement (binder) used. This research, shows that RBM performed well compared to RCS, but no significant effect of different asphalt cement. The similar result was gain by the same author on different research which entitles Application of Gray Relational Analysis to Evaluate HMA with Reclaimed Building Materials [8].

From the sources, it can be concluded that throughout the project, the mechanical behavior of recycled-aggregate concrete was tested out on specimens manufactured by fully replacing natural with recycled aggregates. A course and fine fraction of recycled aggregate will be used. These fractions were directly taken after debris from building demolition is currently disposed ads suitably selected, ground, cleans and sieved.

CHAPTER 3

METHODOLOGY/PROJECT WORK

3.1 Project work

Start

Research

Literature Review

Building Demolition Classification

Performance of Recycle Aggregate Test

Check Requirements of Local Specifications

Final Report

End

Figure 3.1: Project Activities Flow

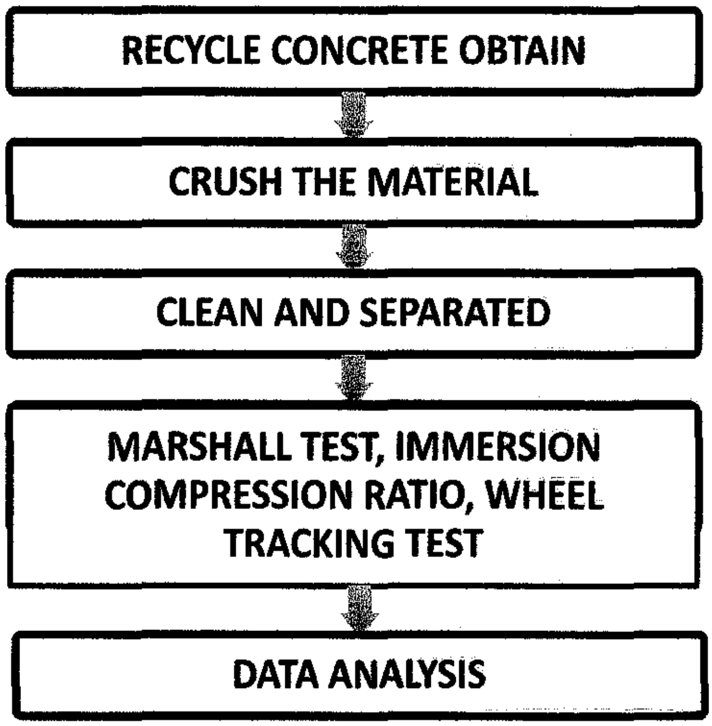

Figure 3.2: Recycling Test Detail

The project is a study base project that involves several laboratory test related to asphalt concrete. Specifically, it is a study of recycling building demolition as the alternative for natural aggregate in hot mix asphaltic concrete. First and for most, the project will begin with the research on several issues which had been mention in the research methodology below. With the collective information, the project will proceed with the literature review on recycling building demolition. This study will hopefully create a significant impact toward the environment. Besides, the author will discuss a basic knowledge about aggregate in asphalt concrete. It also covers the basic test that should and should not be conducted throughout the project.

After completing the literature review, the further studies will move on to the classification of building demolition. There will be concrete, stone masonry, natural slate, brick, pipes and many other materials left after the construction finish. All the components have different characteristics, advantages and disadvantages to become recycle asphalt concrete. Then, there will be few laboratory tests to assess the performance of recycled aggregate after the suitable waste material from construction had been figure out. The understanding of natural aggregate composition and local specification requirement for the index of retained strength, average net retained strength, loss of stability, wheel tracking rate and other experiment will give a great overview to the whole project besides having a basic knowledge on material waste in building demolition.

Lastly, all the studies and discussion will be compiled in the final report. Apart from that, the result of laboratory result will be further explain and justifies. The operational and safety requirements also can be developed from the study.

3.2 Research Methodology

Research is a method taken in order to gain information regarding the major scope of the project. The sources of the research cover the handbook of building demolition and hot mix asphaltic concrete, e-journal, e-thesis and several trusted link.

The steps of research:

1. Gain information of the major sustainability concern nationally which is solid waste.
2. Focus on the small scope which is building demolition waste.
3. Find the tendency of recycling or reuse the building demolition waste for asphaltic concrete.
4. List down experiment of testing the recycled aggregate
5. Simplify the method used

3.3 Laboratory Test

It is a method of testing with the goal of explaining the nature of reality. For recycle building demolition waste in hot mix asphaltic concrete, some experiment should be done to evaluate the strength of the recycled aggregate.

The recycle concrete will be taken from the construction area nearby as well as taking fragments of concrete from the Concrete Laboratory at UTP.

The lists of related laboratory test are:

1. Sieve Analysis
2. Marshall Test

Figure 3.3 : Marshall Flow and Density Equipment and Marshall Specimen

3.4 Activities/Gantt Chart and Milestone

No	Detail/Week	1	2	3	4	5	6	Mid-Semester Break	7	8	9	10	11	12	13	14
1	Selection of Project Topic: Recycling Building Demolition Waste in Hot-Mix Asphaltic Concrete	●														
2	Preliminary Research Work: Research on literatures related to the topic	●	●	●	●	●	●									
3	Submission of Extended Proposal						●									
4	Project Work: Study on the research scope and method								●	●	●					
5	Seminar															
6	Project work continues: Further investigation on the project and do modification if necessary													●	●	●
7	Viva: Project defense and Progress Evaluation										●					
8	Submission of Draft Report														●	
9	Submission of Final Report															●

Table 3.1: Gantt chart and Key Milestone

CHAPTER 4

RESULT AND DISCUSSION

4.1 Component of Recycling Building Demolition

The first task on the project is to come out with the component of recycling building demolition in Malaysia. A full analysis of construction and demolition waste in Asia' countries had been thoroughly done by Asian Institute of Technology, School of Environment, Resources and Development Thailand. The research shows that the source of construction waste at the project site includes materials such as soil and sand, brick and blocks, concrete and aggregate, wood, metal products, roofing materials, plastic materials and packaging of products. The composition of total waste generation is shown in Figure 4.1, which is percentage by weight. Concrete and aggregate is the largest component with 65.8% [3]. The big number of concrete and aggregate component will give a significant factor to propose this material to replace natural aggregate in the industry.

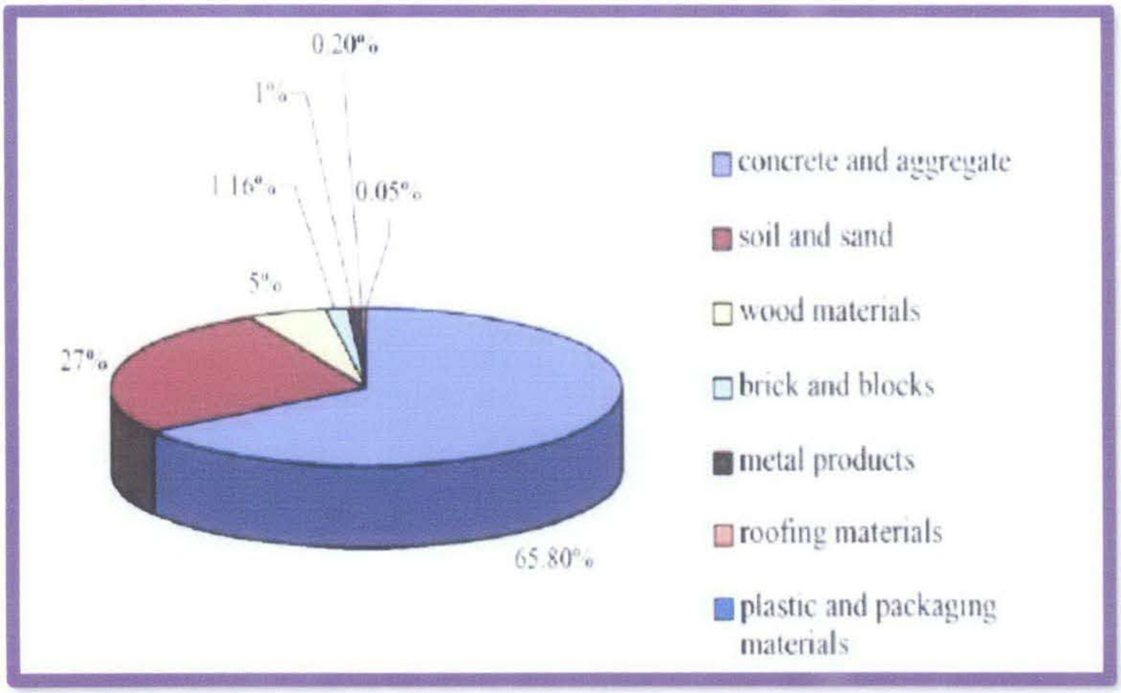

Figure 4.1 : Detail of Construction and Demolition Waste in Malaysia

4.2 Sieve Analysis

Sieve analysis helps to determine the particle size distribution of the coarse and fine aggregates. In this experiment the sieve analysis had been done by following standard by the authority. Sieve size is standardized by the JKR code and so do the passes aggregates through them and thus collect different sized particles left over different sieves.

The Apparatus:

i) A set of sieves of sizes –

- 28 mm
- 20mm
- 14mm
- 10mm
- 5mm
- 3.35mm
- 2.35mm
- 150μm
- 75μm

ii) Balance or scale with an accuracy to measure 0.1 percent of the weight of the test sample. The weight of sample available should not be less than the weight given below:-

Coarse Aggregate : 2000 g

Sand : 500 g

Procedure to determine particle size distribution of Aggregates:

i) The test sample is dried for 24 hours at a temperature of 160°.

ii) The sample is sieved by using a set of JKR Sieves.

iii) On completion of sieving, the material on each sieve is weighed.

iv) Cumulative weight passing through each sieve is calculated as a percentage of the total sample weight.

v) Fineness modulus is obtained by adding cumulative percentage of aggregates retained on each sieve and dividing the sum by 100.

Reporting of Results

The results should be calculated and reported as:

i) the cumulative percentage by weight of the total sample

ii) the percentage by weight of the total sample passing through one sieve and retained on the next smaller sieve, to the nearest 0.1 percent. The results of the sieve analysis may be recorded graphically on a semi-log graph with particle size as abscissa (log scale) and the percentage smaller than the specified diameter as ordinate.

Result of the Experiment

Sieve analysis determines the gradation or distribution of aggregate particle sizes within a given sample. Sieves are shaken in a mechanical shaker for approximately 10 minutes, or the minimum time determined to provide complete separation for the sieve shaker being used [9]. The sieving result are shown in Table 4.1 and illustrated in Figure 4.2 for natural aggregate, and Table 4.3 and Figure 4.3 for recycle aggregate as follow.

Sieve Size (mm)	Cumulative Passing (%)	Retained (%)
28	100	0.00
20	98.69	1.31
14	71.56	27.13
10	59.59	11.97
5	57.32	2.27
3.35	57.00	0.32
2.35	44.52	12.48
0.15	9.97	34.55
0.075	6.00	3.97
Filler	0	6.00
	TOTAL	100

Table 4.1: Sieve Analysis Result for Control Sample

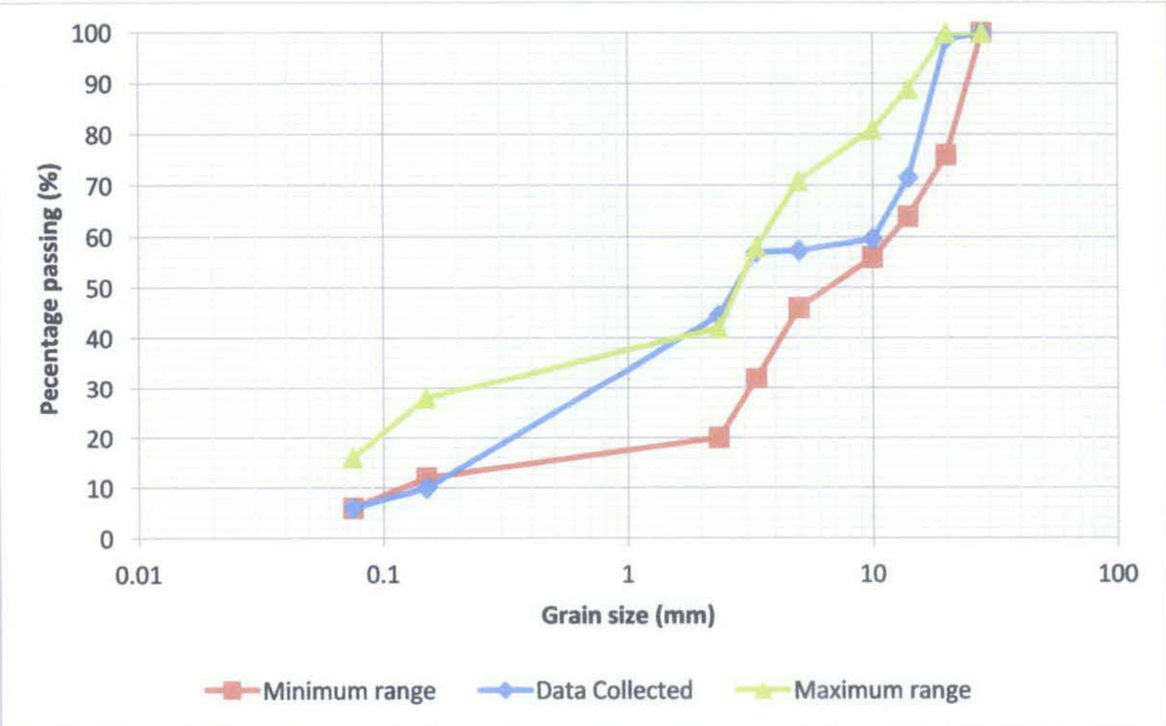

Figure 4.2: Particle Size Distribution of Natural Aggregate

From the distribution of aggregate for the control sample, specific quantity of aggregate are determined for the natural aggregate which are:

Coarse Aggregate	: 511.2g
Sand	: 601.2g
Filler	: 87.60g

From Particle Size Distribution curve shown in Figure 4.2, this aggregate type can be classified as gap-graded due to the deficiency of a certain particle size of the aggregate. It can be noted at between 3.35mm to 5mm sieve size where only 0.32% of aggregate type is retained while there are 34.55% retained on 0.15mm sieve. Therefore, the big difference between these two sizes of retained particle has classified the aggregate soil type as gap-graded. Based on the result shown in Table 4.1 and Particle Size Distribution curve in Figure 4.2, there is 40.41% of the total soil not passing 5mm sieve while 59.59% passed through 5mm sieve. Aggregate that did not pass 5mm sieve is categorized under 'coarse aggregate' while more than finer than 5mm sieve is classified as 'fine aggregate' [10].

The table below shows the JKR standard for Gradation for Asphaltic Concrete.

Gradation for Asphaltic Concrete

Sieve Size	Percentage by Weight Passing
28	100
20	76-100
14	64-89
10	56-81
5	46-71
3.35	32-58
2.35	20-42
0.15	12-28
0.075	6-16
Filler	4-8

Table 4.2: JKR Standard for Asphaltic Concrete

Otherwise, the sieve analysis also been done to the recycle aggregate and the result are as followed:

Sieve Size (mm)	Cumulative Passing (%)	Retained (%)
28	100.00	0.00
20	90.31	9.69
14	78.22	12.09
10	70.86	7.36
5	59.90	10.96
3.35	48.56	11.34
2.35	39.20	9.36
0.15	11.02	28.18
0.075	6.30	4.71
Filler	0	6.30
	TOTAL	100

Table 4.3: Sieve Analysis Result for Recycle Aggregate

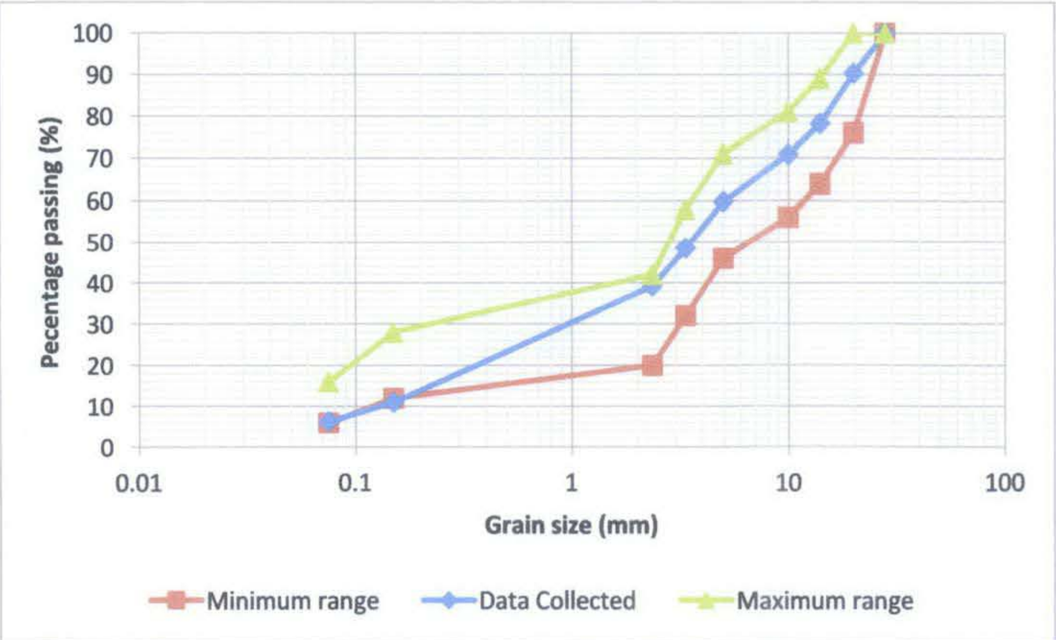

Figure 4.3: Particle Size Distribution of Recycle Aggregate

From Particle Size Distribution curve shown in Figure 4.3, this aggregate type can also be classified as gap-graded due to the deficiency of a certain particle size of the aggregate but the gap is better than the natural aggregate as it nearly covered all the grain size equally. It can be noted at between 0.075mm to 0.15mm sieve size where only 4.71% of aggregate type is retained while there are 28.18% retained on 0.15mm sieve. Therefore, the big difference between these two sizes of retained particle still classified this sample aggregate type as gap-grade. Based on the result shown in Table 4.3 and Particle Size Distribution curve in Figure 4.3, there is 46% of the total aggregate is coarse aggregate while 63% classified as fine aggregate [10].

4.2 MARSHALL TEST

The objective of this test is to determine optimum binder content and compare the component of sample in terms of stability, flow, stiffness, air void percentage and density. The binder content are varies as followed:

- 5%
- 5.5%
- 6%
- 6.5%
- 7%
- 7.5%
- 8%

Procedure to determine Marshall Stability of bituminous mixture

i) Heat the weighed aggregates and the bitumen separately up to 170oC and 163oC respectively.

ii) Mix them thoroughly, transfer the mixed material to the compaction mould arranged on the compaction pedestal.

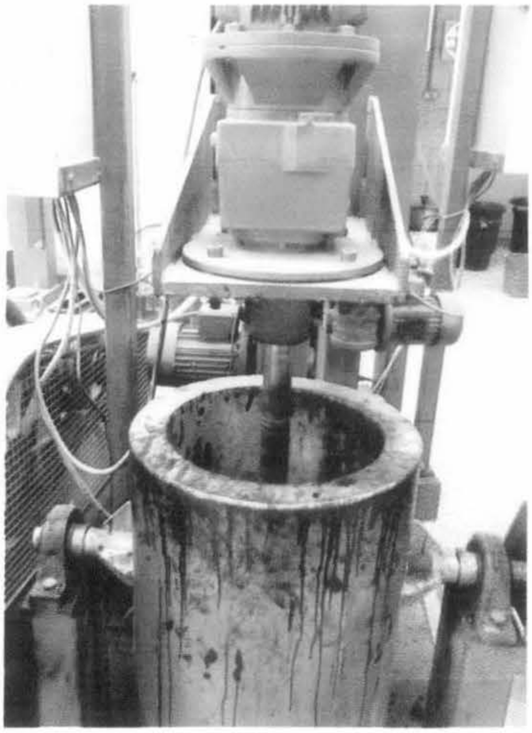

Figure 4.4 : Mechanical Mixer

iii) Give 75 blows on the top side of the specimen mix with a standard hammer (45cm, 4.86kg). Reverse the specimen and give 75 blows again. Take the mould with the specimen and cool it for a few minutes.

iv) Remove the specimen from the mould by gentle pushing. Mark the specimen and cure it at room temperature, overnight.

v) A series of specimens are prepared by a similar method with varying quantities of bitumen content, with an increment of 0.5% (3 specimens).

vi) Before testing of the mould, keep the moulds in the water bath having a temperature of 60oC for half an hour.

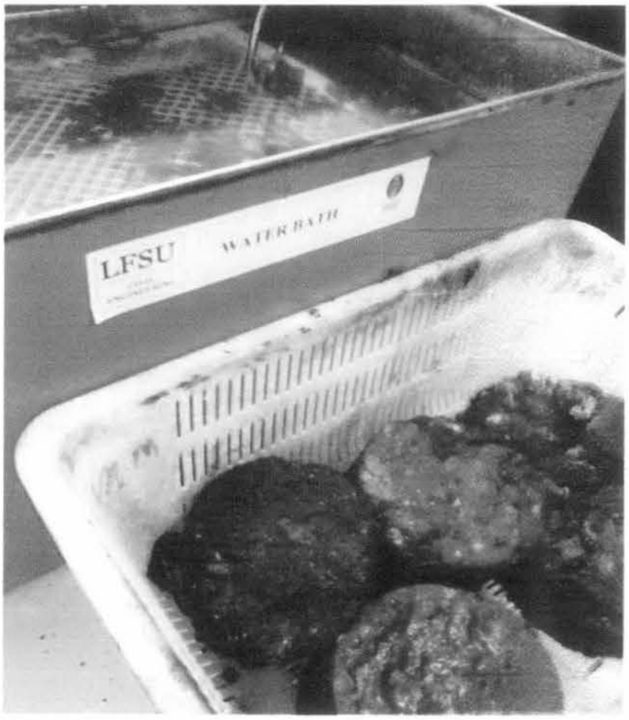

Figure 4.5 : Bath the mould before testing

vii) Check the stability of the mould on the Marshall Stability apparatus.

Figure 4.6 : Marshall Stability apparatus

Results for Control Sample

Bitumen Content	Height (mm)	Specimen	Height (mm)	Mass of Specimen In Air (g)	Mass of Specimen In Water (g)	Volume (cm³)	Specific Gravity Bulk (Density)	Specific Gravity Theory	AC by Volume (%)	Air Voids (%) Total Mix (VIM)	Air Voids (%) Filled with Binder	flow (mm)	Stability (kN) Measured	Stability (kN) C.F	Stability (kN) Corrected	Stiffness (N/mm)	Stiffness (kg/mm)
a	a	b	c	d	e	f	g	h	i	j	k	m	n	o	p	q	r
	5	4	74	1134	606	523	2.15		10.33	11.95	0.46	2.19	3.59	0.96	3.45	1573.70	160.418
5%	5	3	73	1135	610	525	2.16		10.39	11.37	0.48	2.45	3.5	0.96	3.36	1371.43	139.799
	5	2	74	1129	615	514	2.20		10.56	9.95	0.51	2.65	3.43	1.00	3.43	1294.34	131.941
	5.00	AVG	73.67	1132.67	610.33	522.33	2.169	2.4393	10.43	11.09	0.49	2.43	3.51	0.97	3.41	1413.16	144.05
	5.5	4	73.5	1173	640	533	2.20		11.64	9.20	0.56	2.47	6.4	0.93	5.95	2409.72	245.639
5.5%	5.5	3	73.5	1179	636	543	2.17		11.48	10.42	0.52	1.98	6.3	0.93	5.86	2959.09	301.64
	5.5	2	74	1187	633	554	2.14		11.33	11.60	0.49	2.3	6.23	0.89	5.54	2410.74	245.743
	5.50	AVG	73.67	1179.67	636.33	543.33	2.172	2.4238	11.48	10.41	0.53	2.25	6.31	0.92	5.79	2593.18	264.34
	6	4	75	1203	648	555	2.17		12.51	10.01	0.56	2.12	9.13	0.89	8.17	3853.87	392.851
6%	6	3	74.5	1208	655	553	2.16		12.60	9.31	0.58	2.17	9.27	0.89	8.25	3801.98	387.562
	6	2	75	1206	651	555	2.17		12.54	9.79	0.56	2.28	9.38	0.89	8.35	3661.49	373.241
	6.00	AVG	74.83	1205.67	651.33	554.33	2.175	2.4087	12.55	9.70	0.56	2.19	9.28	0.89	8.26	3772.45	384.55
	6.5	4	75.5	1240	671	569	2.16		13.62	8.97	0.60	1.64	7.13	0.86	6.17	3355.87	342.087
6.5%	6.5	3	75	1233	668	565	2.16		13.64	8.84	0.61	2.11	7.27	0.86	6.25	2963.13	302.052
	6.5	2	75	1246	673	573	2.17		13.59	9.16	0.60	2.05	6.69	0.86	5.75	2806.54	286.089
	6.50	AVG	75.17	1239.67	670.67	569.00	2.179	2.3939	13.62	8.99	0.60	2.00	7.05	0.86	6.06	3041.84	310.08
	7	4	74	1283	699	584	2.20		14.79	7.67	0.66	2.19	5.01	0.78	3.91	1784.38	181.894
7%	7	3	75.5	1291	698	593	2.16		14.65	8.50	0.63	2.14	5.2	0.76	3.95	1846.73	188.25
	7	2	75.5	1299	694	605	2.15		14.45	9.76	0.60	2.32	4.94	0.76	3.75	1618.28	164.962
	7.00	AVG	75.00	1291.00	697.00	594.00	2.174	2.3794	14.63	8.65	0.63	2.22	5.05	0.77	3.87	1743.80	178.37
	7.5	4	76	1298	711	587	2.21		15.95	6.51	0.71	2.81	4.93	0.78	3.85	1368.47	139.497
	7.5	3	74	1321	701	620	2.13		15.37	9.92	0.61	2.65	4.66	0.76	3.54	1336.45	136.234
	7.5	2	75.00	1301	700	601	2.16		15.61	8.48	0.65	2.78	4.73	0.78	3.69	1327.12	135.283
7.5%	7.50	AVG	75.00	1306.67	704.00	602.67	2.169	2.3652	15.64	8.30	0.66	2.75	4.77	0.77	3.69	1344.01	137.00
	8	4	75	1316	701	615	2.14		16.46	9.00	0.65	3	4.22	0.76	3.21	1069.07	108.977
	8	3	77	1322	703	619	2.14		16.43	9.17	0.64	2.89	4.17	0.76	3.17	1036.61	111.785
	8	2	77	1309	716	593	2.21		16.98	6.12	0.73	3.32	4.5	0.81	3.65	1097.89	111.916
8%	8.00	AVG	76.33	1315.67	706.67	609.00	2.161	2.3514	16.62	8.10	0.67	3.07	4.30	0.78	3.34	1087.86	110.89

Table 4.4: Result for Control Sample (Natural Coarse Aggregate used

Result Analysis for Control Sample (Using Natural Coarse Aggregate)

% of Bitumen	Density (kg/m³)
5	2.169
5.5	2.172
6	2.175
6.5	2.179
7	2.174
7.5	2.169
8	2.161

Table 4.5: Density for Control Sample

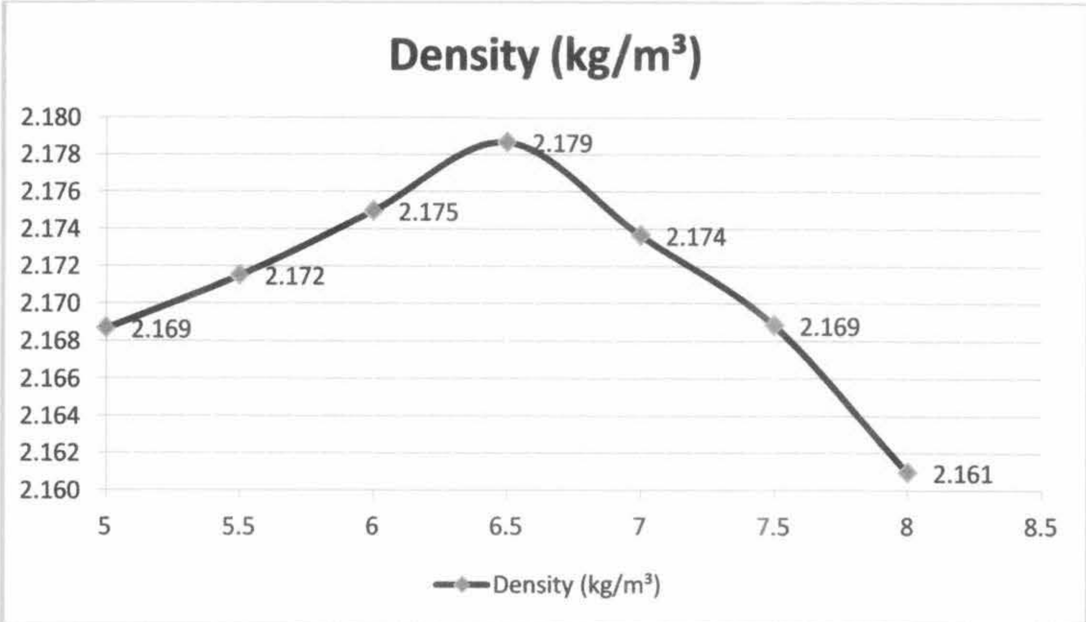

Figure 4.7: Density for Natural Coarse Aggregate

From the density graph at Figure 4.7, the maximum density is when the bitumen content is 6.5%. The value of density is 2.179kg/m³.

% of Bitumen	Stability (kN)
5	3.41
5.5	5.79
6	8.26
6.5	6.06
7	3.87
7.5	3.69
8	3.34

Table 4.6: Marshall Stability for Control Sample

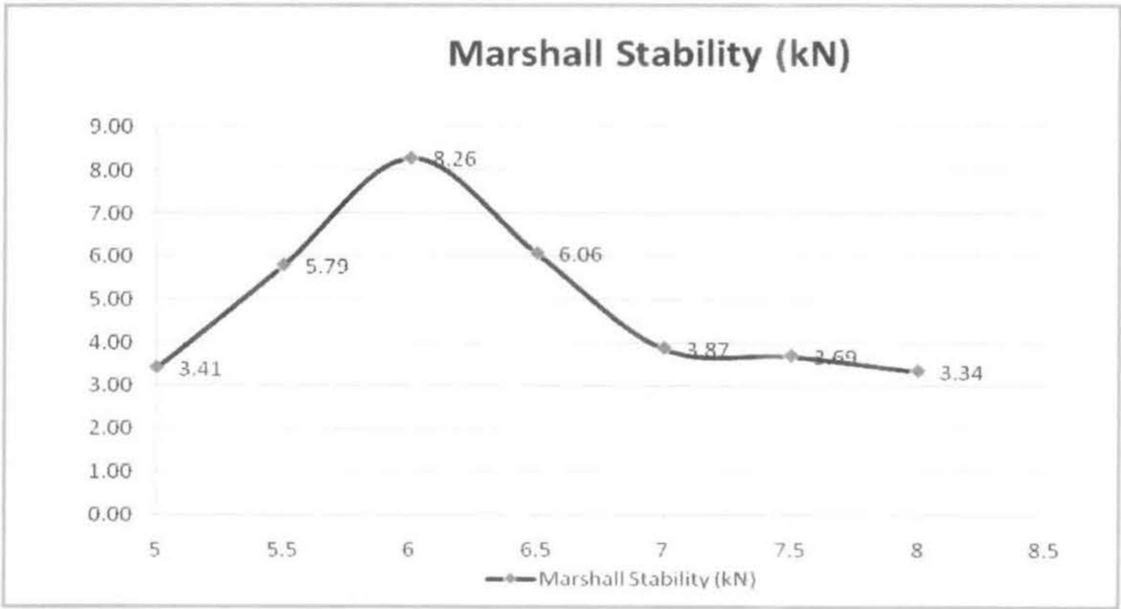

Figure 4.8: Marshall Stability for Natural Coarse Aggregate

From Figure 4.8, for Marshall Stability, the optimum bitumen content is when it is 6% and the value is 8.25kN.

% of Bitumen	VIM (%)
5	11.09
5.5	10.41
6	9.70
6.5	8.99
7	8.65
7.5	8.30
8	8.10

Table 4.7: Percentage of Air Void for Control Sample

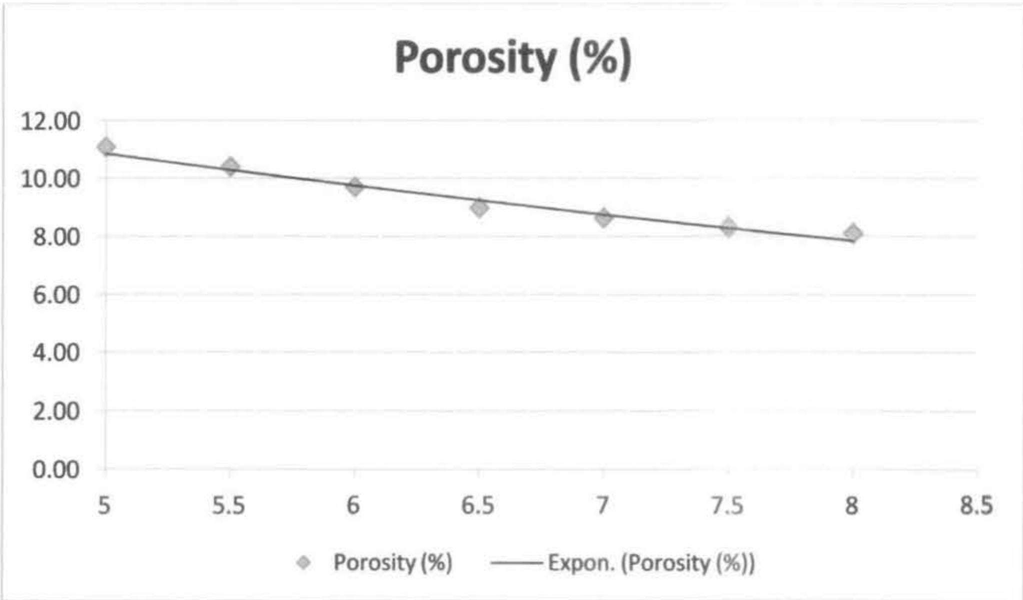

Figure 4.9: Porosity for Natural Coarse Aggregate

And from the porosity or air void test on Figure 4.9, the nearest bitumen content that corresponding to the median of designed limits of percent air voids (Vv) in the total mix which is 3.5% is 8% bitumen content.

So, to determine the optimum bitumen content of the whole natural aggregate experiment is by calculating the average of the results of maximum stability, maximum density and correspond bitumen content at 3.5% air void [11].

- Binder content corresponding to maximum stability, A
- Binder content corresponding to maximum bulk specific gravity, B
- Binder content corresponding to the median of designed limits of percent air voids in the total mix, C

$$\mathbf{OBC = \frac{A + B + C}{3}}$$

$$OBC = \frac{6 + 6.5 + 8}{3}$$

$$OBC = 6.83\%$$

Based on the calculation of the major factors to determine Optimum Bitumen Content, it can be concluded that the OBC for the sample that used natural aggregate is 6.83%.

After the OBC had been analyzed, the value will be checked whether it meets other JKR guideline in Standard Specification for road Work (JKR/SPJ/rev2005) which is as followed:

- Stability >6200N
- Within flow limit (2-4mm)
- Maximum Stiffness (>280kg/mm)
- The porosity is on the range of 3%-5%

% of Bitumen	Flow (mm)
5	2.43
5.5	2.25
6	2.19
6.5	2.00
7	2.22
7.5	2.75
8	3.07

Table 4.8: Marshall Flow for Control Sample

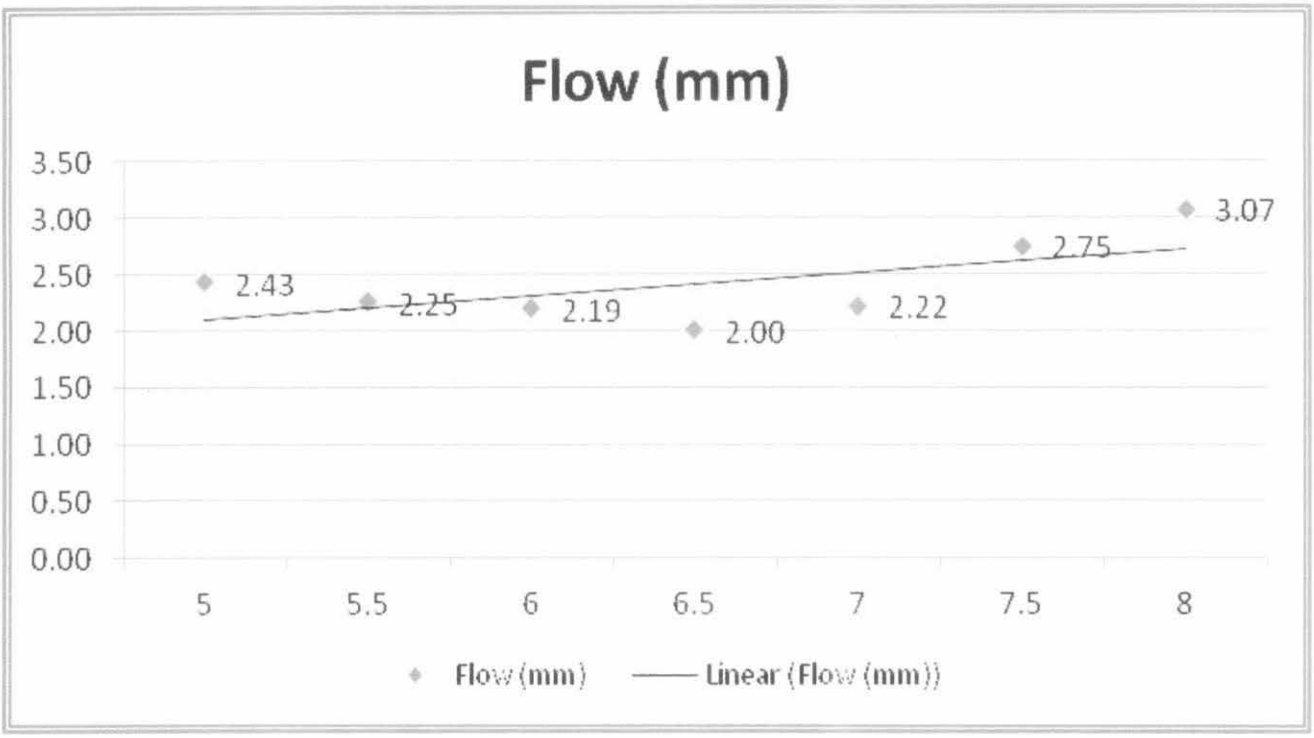

Figure 4.10: Flow for Natural Coarse Aggregate

The flow limit shows the interlock between the aggregate. The better flow shows the better interlock between particles.

% of Bitumen	Stiffness (kg/mm)
5	144.05
5.5	264.34
6	384.55
6.5	310.08
7	178.37
7.5	137.00
8	110.89

Table 4.9: Marshall Quotient (Stiffness) for Control Sample

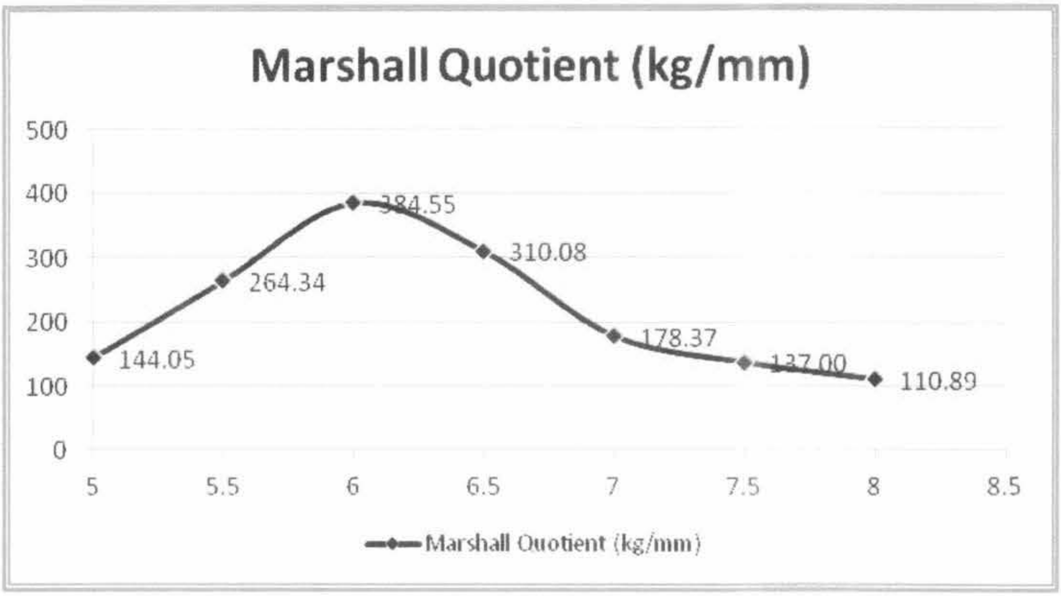

Fig. 4.11: Marshall Quotient for Natural Coarse Aggregate

The Marshall Quotient is actually showing the stiffness of the sample. The stiffness shows the resistance of an elastic body to deformation. So, the higher number of stiffness will is better. The Marshall Quotient is around 280kg/mm when the bitumen content is 6.8%. So, it is within the range.

From all of the graphs, it can be concluded that bitumen content 6.8% of the recycle aggregate meet all the specification except the porosity is out of range which is above 8%. The porosity should be in the range is of 3-4% only. The higher porosity means there are excess of spaces between grains that is over the limit. Just like the control sample that has the same problem, some modification should be taken to adjust the result.

Results for Recycled Coarse Aggregate

Bitumen Content	Height (mm)	Speci-men	Height (mm)	Mass of Specimen: in Air (g)	in Water (g)	Volume (cm³)	Specific Gravity: Bulk (Density)	Theory	AC by Volume (%)	Air Voids (%): Total Mix (VMA)	Filled with Binder	Flow (mm)	Stability (kN): Measured	C.F	Corrected	Stiffness: (N/mm)	(kg/mm)
5%	5	A	74	1155.9	631.9	564	2.12		10.19	15.87	0.39	2.22	7.16	0.81	5.80	2512.43	256.3
	5	B	73	1201.2	643.8	557.4	2.16		10.36	14.50	0.42	3.76	13.99	0.81	11.33	3013.80	307.22
	5	C	74	1190.1	630.5	559.6	2.13		10.22	15.62	0.40	3.11	11.31	0.81	9.16	2945.69	300.27
	5.00	AVG	73.67	1195.73	635.40	560.33	2.134	2.5204	10.26	15.33	0.40	3.03	10.82	0.81	8.76	2857.31	291.26
5.5%	5.5	A	73.5	1183.1	651.3	531.3	2.22		11.77	11.14	0.51	2.31	9.63	0.81	7.80	3376.75	344.22
	5.5	B	73.5	1246.8	674.1	572.7	2.18		11.51	13.04	0.47	4.74	18.37	0.81	14.88	3594.13	366.37
	5.5	C	74	1190.6	620.8	569.8	2.09		11.05	16.54	0.40	2.11	10.19	0.81	8.25	3911.80	398.76
	5.50	AVG	73.67	1206.83	648.73	558.10	2.164	2.5035	11.44	13.57	0.46	2.85	12.73	0.81	10.31	3627.56	369.78
6%	6	A	75	1281.8	655.4	586.4	2.19		12.61	12.11	0.51	2.48	15.89	0.81	12.87	5169.88	529.04
	6	B	74.5	1250.5	673.5	577	2.17		12.50	12.86	0.49	2.66	18.54	0.81	15.02	5645.64	575.5
	6	C	75	1288.1	637	591.1	2.18		12.57	12.38	0.50	2.34	15.45	0.81	12.51	5348.08	545.17
	6.00	AVG	74.83	1273.47	688.63	584.83	2.177	2.4870	12.56	12.45	0.50	2.49	16.63	0.81	13.47	5394.53	549.90
6.5%	6.5	A	75.5	1274.6	690.1	584.5	2.18		13.63	11.74	0.54	4.46	18.79	0.78	14.65	3286.14	334.98
	6.5	B	75	1257.1	689.4	567.7	2.21		13.84	10.38	0.57	3.77	21.63	0.81	17.52	4647.29	473.73
	6.5	C	75	1260.7	679.8	580.9	2.17		13.56	12.17	0.53	3.81	22.31	0.81	18.07	4743.07	483.49
	6.50	AVG	75.17	1264.13	686.43	577.70	2.188	2.4709	13.68	11.43	0.55	4.01	20.91	0.80	16.75	4225.50	430.73
7%	7	A	74	1270.6	696.1	574.5	2.21		14.89	9.91	0.60	3.33	11.09	0.81	8.98	2697.57	274.98
	7	B	75.5	1286.3	700.2	586.1	2.19		14.77	10.61	0.58	3.25	9.91	0.81	8.03	2469.88	251.77
	7	C	75.5	1289.9	690.9	599	2.15		14.49	12.29	0.54	3.41	11.32	0.78	8.83	2589.33	263.95
	7.00	AVG	75.00	1282.27	695.73	586.53	2.187	2.4551	14.72	10.94	0.57	3.33	10.77	0.80	8.61	2585.59	263.57
7.5%	7.5	A	76	1322.5	709.4	613.1	2.16		15.56	11.58	0.57	4.22	8.53	0.78	6.65	1576.64	160.72
	7.5	B	74	1308.8	708.1	600.7	2.18		15.74	10.56	0.60	3.79	11.88	0.81	9.62	2539.00	253.82
	7.5	C	75.00	1305.19	705.08	600.11	2.17		15.68	10.85	0.59	3.78	10.39	0.78	8.11	2144.89	218.64
	7.50	AVG	75.00	1312.83	708.19	604.64	2.171	2.4396	15.66	11.00	0.59	3.93	10.27	0.79	8.13	2086.84	212.73
8%	8	A	75	1244.6	668.8	575.8	2.16		16.63	10.85	0.61	4.43	7.7	0.81	6.24	1407.90	143.52
	8	B	77	1283.5	688.3	595.2	2.16		16.59	11.06	0.60	3.21	12.04	0.81	9.75	3036.13	309.7
	8	C	77	1280.1	670.1	610	2.10		16.14	13.45	0.55	3.55	8.4	0.78	6.55	1845.63	188.14
	8.00	AVG	76.33	1269.40	675.73	593.67	2.139	2.4245	16.45	11.78	0.58	3.73	9.38	0.80	7.51	2097.22	213.78

Table 4.10: Result for Recycled Coarse Aggregate

Results for Control Sample

% of Bitumen	Density
5	2.134
5.5	2.164
6	2.177
6.5	2.188
7	2.187
7.5	2.171
8	2.139

Table 4.11: Density for Recycled Concrete Sample

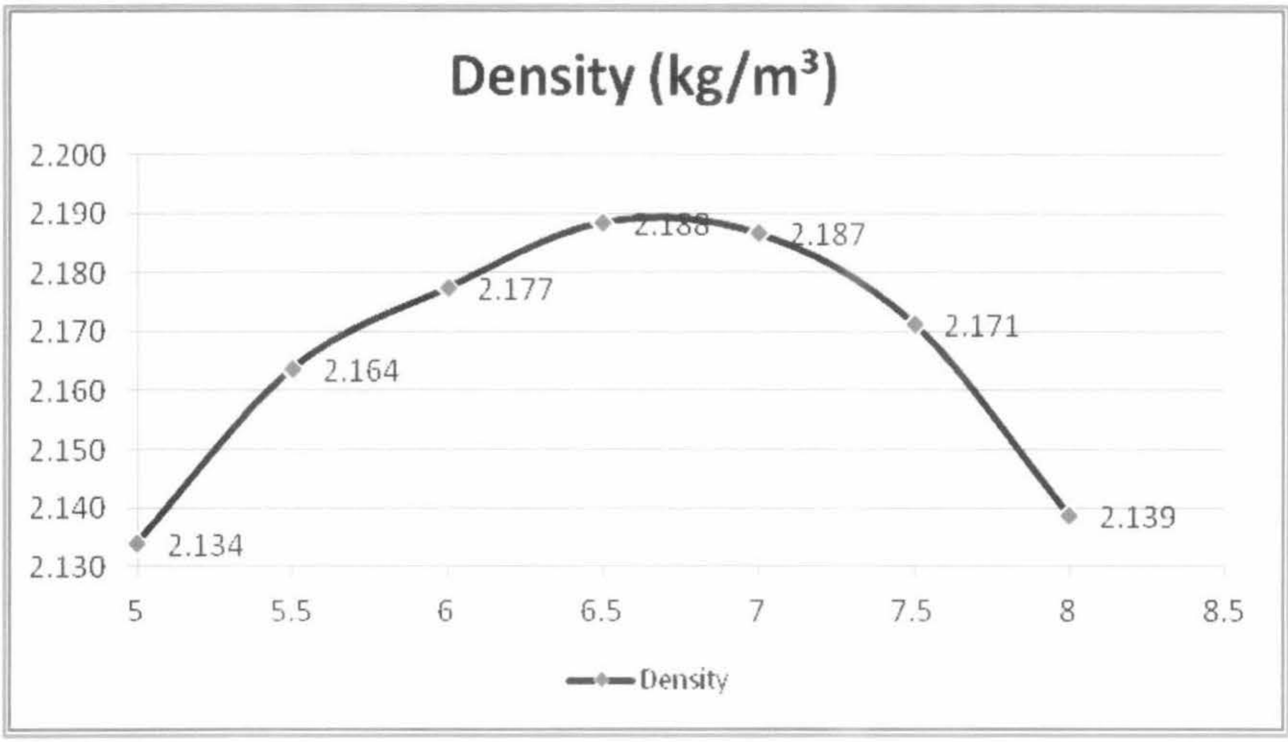

Figure 4.12: Density for Recycle Coarse Aggregate

The density graph at Figure 4.12 shows that the maximum density is when the bitumen content is 7.0%. The value of density is 2.188kg/m^3.

% of Bitumen	Stability
5	8.76
5.5	10.31
6	13.47
6.5	16.75
7	8.61
7.5	8.13
8	7.51

Table 4.12: Marshall Stability for Recycled Concrete Sample

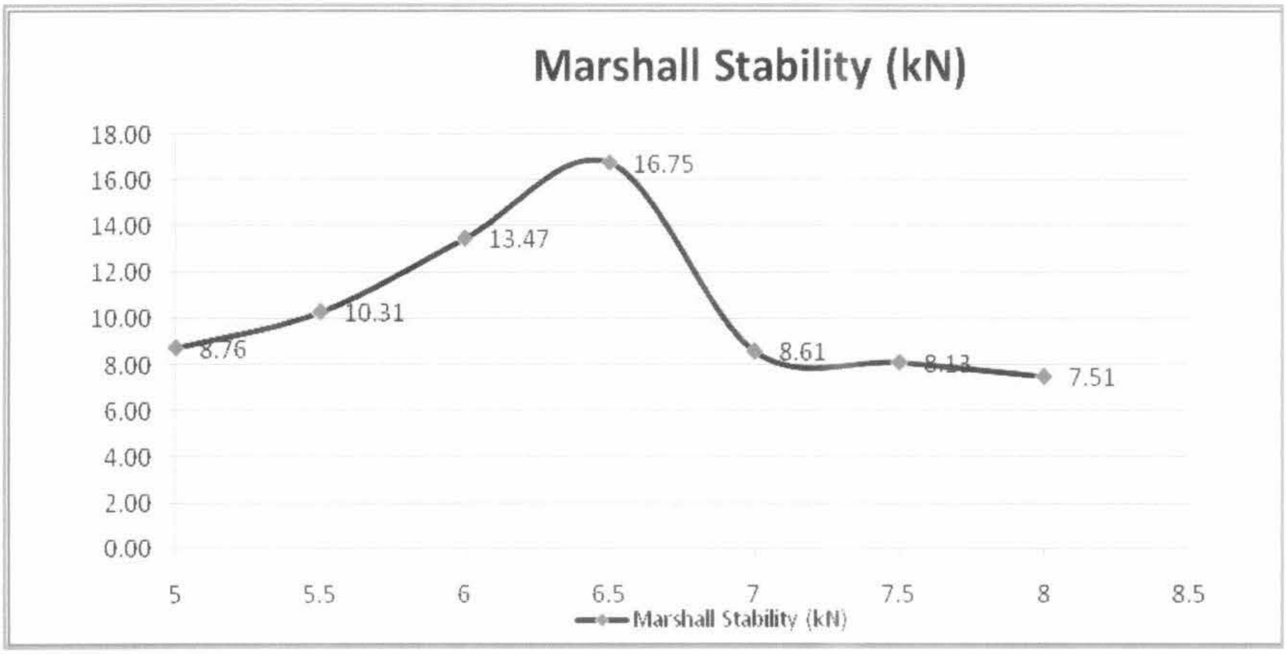

Figure 4.13: Marshall Stability for Recycle Coarse Aggregate

From Figure 4.13, for Marshall Stability, the optimum bitumen content is when it is 6.5% and the value is 16.75kN. The value is actually two times larger than the Marshall Stability in natural coarse aggregate.

% of Bitumen	VIM
5	15.33
5.5	13.57
6	12.45
6.5	11.43
7	10.94
7.5	11.00
8	11.78

Table 4.13: Percentage of Air Void for Recycled Concrete Sample

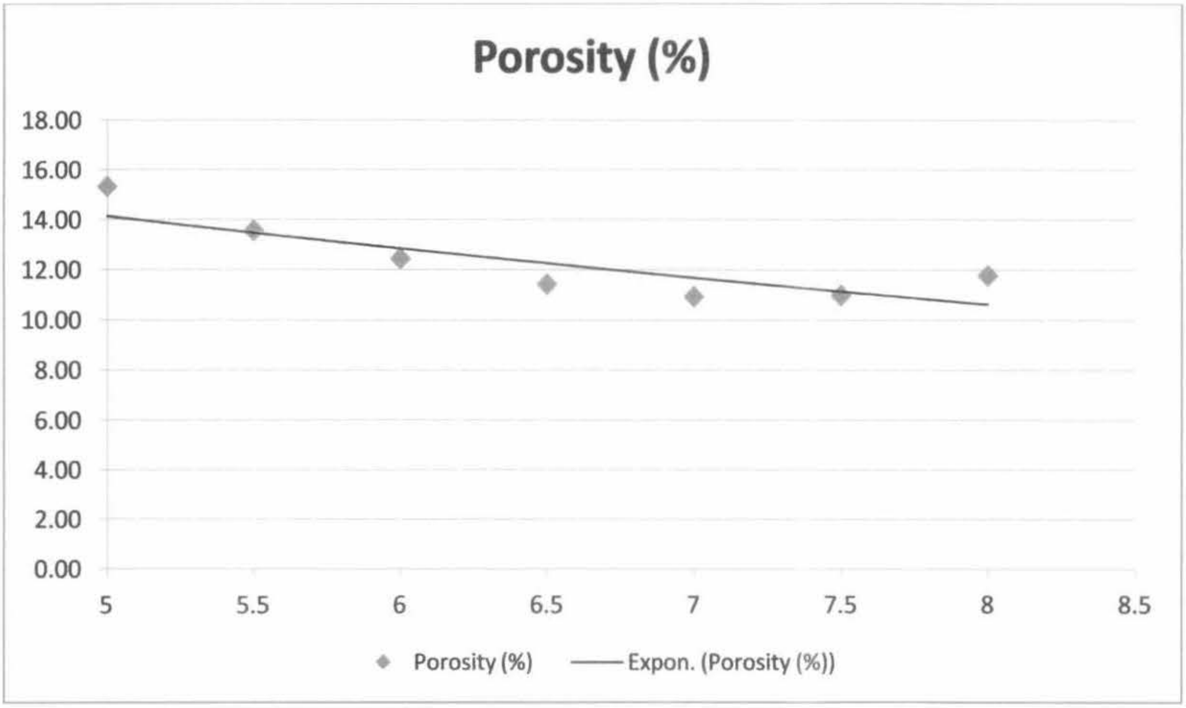

Figure 4.14: Porosity for Recycle Coarse Aggregate

The porosity or air void test on Figure 4.14 shows that the nearest bitumen content that corresponding to the median of designed limits of percent air voids in the total mix (3.5%) is 8%.

So, to determine the optimum bitumen content of the whole natural aggregate experiment is by calculating the average of the results of maximum stability, maximum density and correspond bitumen content at 3.5% air void [11]

- Binder content corresponding to maximum stability, A
- Binder content corresponding to maximum bulk specific gravity, B
- Binder content corresponding to the median of designed limits of percent air voids in the total mix, C

$$\mathbf{OBC = \frac{A + B + C}{3}}$$

$$OBC = \frac{6.5 + 6.5 + 7}{3}$$

$$OBC = 6.67\%$$

It shows that the OBC for the sample that used natural aggregate is 6.2%.

After the OBC had been analyzed, the value will be checked whether it meets other JKR guideline in Standard Specification for road Work (JKR/SPJ/rev2005) which is as followed:

- Stability >6200N
- Within flow limit (2-4mm)
- Maximum Stiffness (>280kg/mm)
- The porosity is on the range of 3%-5%

% of Bitumen	Flow
5	3.03
5.5	2.85
6	2.49
6.5	4.01
7	3.33
7.5	3.93
8	3.73

Table 4.14: Marshall Flow for Recycled Concrete Sample

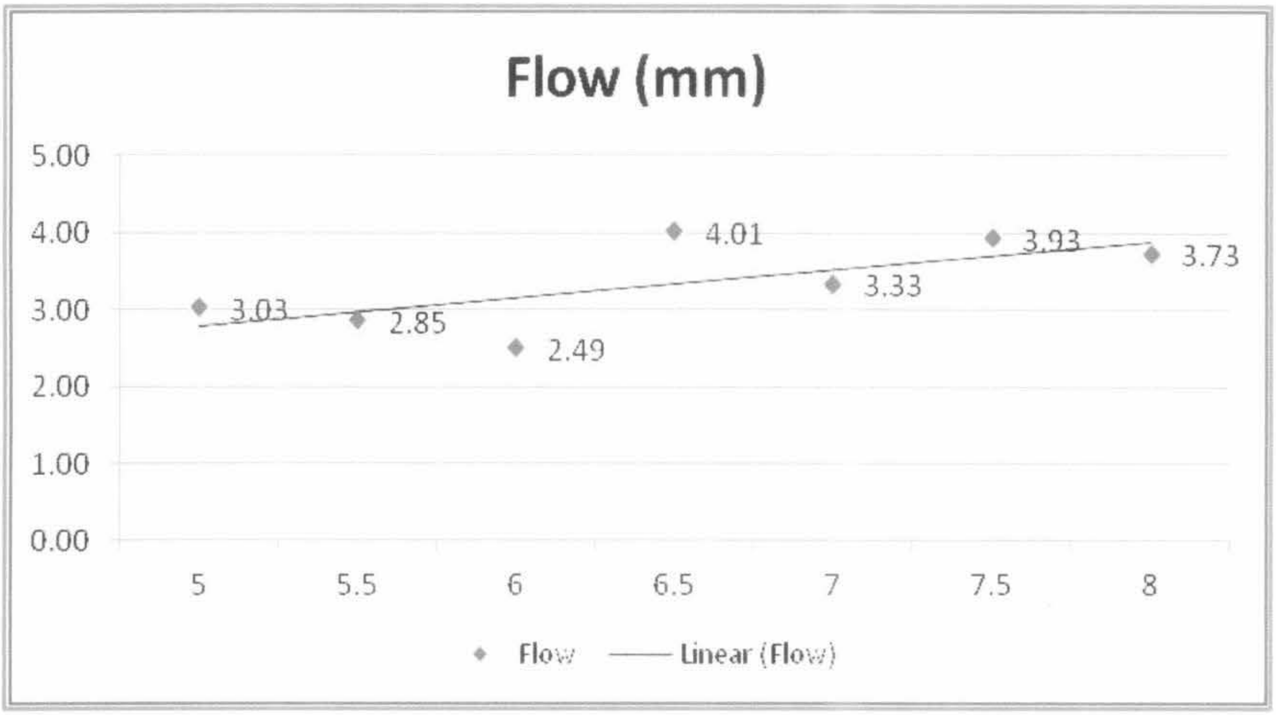

Figure 4.15: Flow for Recycle Coarse Aggregate

As the greater number of flow shows the better interlock between particles, so, the best flow is when the bitumen is 6%.

% of Bitumen	Stiffness
5	291.26
5.5	369.78
6	549.90
6.5	430.73
7	263.57
7.5	212.73
8	213.78

Table 4.15: Marshall Quotient (Stiffness) for Recycled Concrete Sample

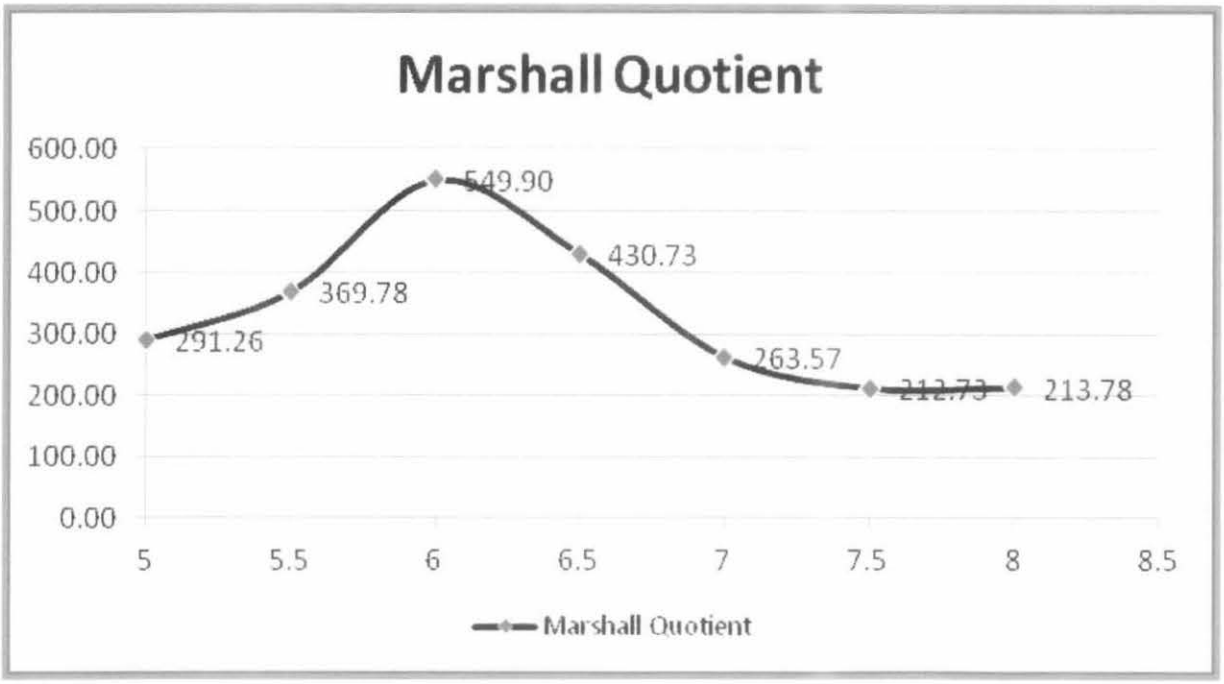

Figure 4.16: Marshall Quotient for Recycle Coarse Aggregate

The stiffness shows that shows the resistance of an elastic body to deformation shows that the stiffness is more than 280kg/mm when it is 6.67%.

When the bitumen content is around 6.67%, the Marshall Quotient or stiffness is nearly 400kg/mm. The stiffness of natural coarse aggregate will give nearly 380kg/mm, so it is a big increase in stiffness when the recycle aggregate is used.

From all of the graphs, it can be concluded that bitumen content 6.67% of the recycle aggregate meet all the specification except the porosity is out of range which is above 10%. The porosity should be in the range is of 3-4% only. The higher porosity means there are excess of spaces between grains that is over the limit. Just like the control sample that has the same problem, some modification should be taken to adjust the result.

CHAPTER 5

CONCLUSION

In 21st Century, many buildings being demolished and reconstructed in Malaysia. Most of the demolition debris is currently disposed off in landfill sites. There are 177 disposal sites in Peninsular Malaysia which cover 20 million populations. It shows that these sites have limited capacities and are required for other competing types of wastes which cannot be recycled [12]

On the same time, the sources of natural aggregate are depleting and hence the imported aggregate is costly. Recycling the building demolition waste can provide a timely opportunity to reduce the problem of disposing off the demolition waste and the aggregate scarcity. This study is conducted to evaluate the use of aggregate obtained from building demolition waste in a hot mix asphaltic concrete.

The attempt to improve the quality of the aggregates for concrete by using recycle aggregate as alternative allowed achieving surprising and unexpected performance of the asphalt concrete.

RECOMMENDATION

Regardless the results of present study, some improvement in this area can be done especially on the air void problem. If the mix design for the optimum binder content does not satisfy some of the requirements of specifications, it is necessary to adjust the original blend of aggregates.

If high voids (more than 5%), it is necessary to increase the amount of mineral filler in the mix to cater the air void problem.

Other than that, I also recommend the study on recycling building demolition in hot mix asphaltic concrete should be continue with other relevant test for example creep test and wheel tracking test for a firm justification and analysis in a future.

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APPENDIX I

Calculation for Bulk Specific Gravity of Aggregate (Gbam)

Since the aggregate mixture consists of different fractions of coarse aggregate, fine aggregate, and mineral filler with different specific gravities, the bulk specific gravity of the total aggregate in the paving mixture is given as

$$G_{bam} = \frac{P_{ca} + P_{fa} + P_{mf}}{\frac{P_{ca}}{G_{bca}} + \frac{P_{fa}}{G_{bfa}} + \frac{P_{mf}}{G_{bmf}}}$$

where,

G_{bam} = bulk specific gravity of aggregates in paving mixtures.

P_{ca}, P_{fa}, P_{mf} = percent by weight of coarse aggregate, fine aggregate, and mineral filler in paving mixture.

G_{bca}, G_{bfa}, G_{bmf} = bulk specific gravities of coarse aggregate, fine aggregate, and mineral filler, respectively.

APPENDIX II

Calculation for Percent voids in compacted mineral aggregate (VMA)

The percent voids in mineral aggregate (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

$$VMA = 100 - \frac{G_{bcm}\, P_{ta}}{G_{bam}}$$

where,

VMA = percent voids in mineral aggregates.

G_{bcm} = bulk specific gravity of compacted specimen

G_{bam} = bulk specific gravity of aggregate.

P_{ta} = aggregate percent by weight of total paving mixture.

APPENDIX III

Calculation for Percent air voids in compacted mixture (Pav)

Percent air voids is the ratio (expressed as a percentage) between the volume of the air voids between the coated particles and the total volume of the mixture.

$$P_{av} = 100\,\frac{G_{mp} - G_{bcm}}{G_{mp}}$$

where,

P_{av} = percent air voids in compacted mixture

G_{mp} = maximum specific gravity of the compacted paving mixture

G_{bcm} = bulk specific gravity of the compacted mixtures

APPENDIX IV

Determination of Optimum Bitumen Content

Optimum binder content is selected as the average binder content for maximum density, maximum stability and specified percent air voids in the total mix.

$$B_0 = \frac{B_1 + B_2 + B_3}{3}$$

where,

B_0 = optimum Bitumen content.

B_1 = % asphalt content at maximum unit weight.

B_2 = % asphalt content at maximum stability.

B_3 = % asphalt content at specified percent air voids in the total mix.

APPENDIX V

Stability Correlation Ratios

Volume of specimen, cm^3	Approximate thickness of specimen mm	in.	Correlation ratio
200 to 213	25.4	1	5.56
214 to 225	27.0	1 1/16	5.00
226 to 237	28.6	1 1/8	4.55
238 to 250	30.2	1 3/16	4.17
251 to 264	31.8	1 1/4	3.85
265 to 276	33.3	1 5/16	3.57
277 to 289	34.9	1 3/8	3.33
290 to 301	36.5	1 7/16	3.03
302 to 316	38.1	1 1/2	2.78
317 to 328	39.7	1 9/16	2.50
329 to 340	41.3	1 5/8	2.27
341 to 353	42.9	1 11/16	2.08
354 to 367	44.4	1 3/4	1.92
368 to 379	46.0	1 13/16	1.79
380 to 392	47.6	1 7/8	1.67
393 to 405	49.2	1 15/16	1.56
406 to 420	50.8	2	1.47
421 to 431	52.4	2 1/16	1.39
432 to 443	54.0	2 1/8	1.32
444 to 456	55.6	2 3/16	1.25
457 to 470	57.2	2 1/4	1.19
471 to 482	58.7	2 5/16	1.14
483 to 495	60.3	2 3/8	1.09
496 to 508	61.9	2 7/16	1.04
509 to 522	63.5	2 1/2	1.00
523 to 535	64.0	2 9/16	0.96
536 to 546	65.1	2 5/8	0.93
547 to 559	66.7	2 11/16	0.89
560 to 573	68.3	2 3/4	0.86
574 to 585	71.4	2 13/16	0.83
586 to 598	73.0	2 7/8	0.81
599 to 610	74.6	2 15/16	0.78
611 to 625	76.2	3	0.76

APPENDIX VI

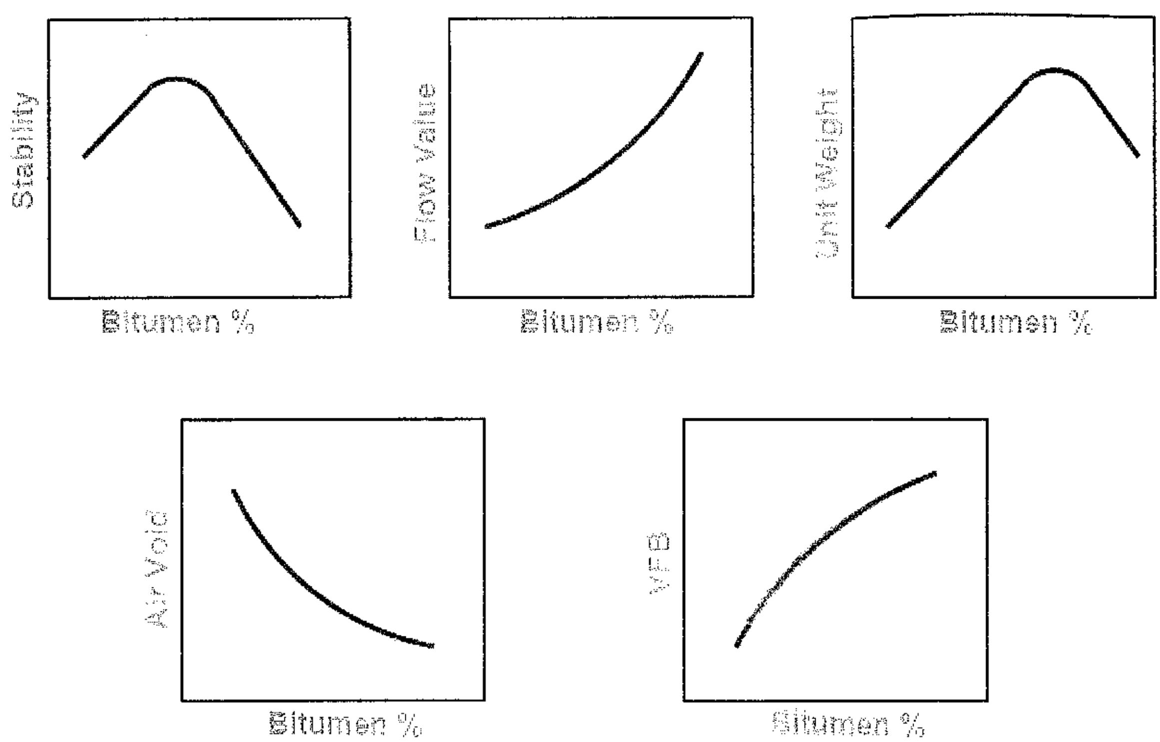
Gradation for Asphaltic Concrete from JKR 2005

Mix Type	Wearing Course	Wearing Course	Wearing Course
Mix Designation	AC 10	AC 14	AC 20
BS Sieve Size. mm	Percentage Passing (by weight)		
28.0			100
20.0		100	76-100
14.0	100	90-100	64-89
10.0	90-100	76-86	56-81
5.0	58-72	50-62	46-71
3.35	48-64	40-54	32-58
1.18	22-40	18-34	20-42
0.425	12-26	12-24	12-28
0.150	6-14	6-14	6-16
0.075	4-8	4-8	4-8

Note: AC20 Gradation obtained from (JKR/SPJ/1988)

APPENDIX VII

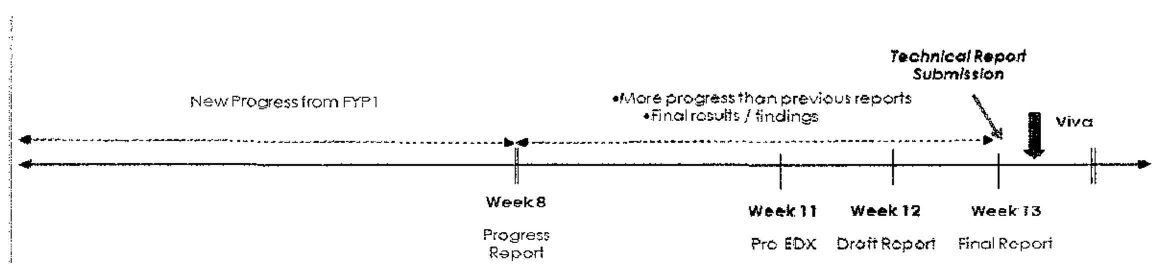
Marshall Graphical Graph



APPENDIX VIII

FYP Gantt Chart

No	Detail/Week	1	2	3	4	5	6		7	8	9	10	11	12	13	14
1	Selection of Project Topic: Recycling Building Demolition Waste in Hot-Mix Asphaltic Concrete	●						Mid-Semester Break								
2	Preliminary Research Work: Research on literatures related to the topic	●	●	●	●	●	●									
3	Submission of Extended Proposal						●									
4	Project Work: Study on the research scope and method								●	●	●					
5	Seminar															
6	Project work continues: Further investigation on the project and do modification if necessary													●	●	●
7	Viva: Project defense and Progress Evaluation										●					
8	Submission of Draft Report														●	
9	Submission of Final Report															●



APPENDIX IX

Detail for Optimum Bitumen Content Determination in Marshall Test

Table 2-4. OBC

Test Property	Type of Mix	Point on Curve		Criteria	
		100-psi Tires[1]	200-psi Tires[1]	100-psi Tires[1]	200-psi Tires[1]
Stability	Asphalt-concrete surface course	Peak of curve	Peak of curve	≥500 lb	≥1,800 lb
	Asphalt-concrete binder course	Peak of curve[2]	Peak of curve[2]	≥500 lb	≥1,800 lb
	Sand asphalt	Peak of curve	---	≥500 lb	---
Unit weight	Asphalt-concrete surface course	Peak of curve	Peak of curve	Not used	Not used
	Asphalt-concrete binder course	Not used	Not used	Not used	Not used
	Sand asphalt	Peak of curve	---	Not used	Not used
Flow	Asphalt-concrete surface course	Not used	Not used	≤20 lb	≤16 lb
	Asphalt-concrete binder course	Not used	Not used	≤20 lb	≤16 lb
	Sand asphalt	Not used	Not used	≤20 lb	≤16 lb
Percent of voids in the total mix	Asphalt-concrete surface course	4 (3)	4 (3)	3-5 (2-4)	3-5 (2-4)
	Asphalt-concrete binder course	5 (4)	6 (5)	4-5 (3-5)	5-7 (4-6)
	Sand asphalt	6 (5)	--- (-)	5-7 (4-6)	--- (-)
Percent of voids filled with bitumen	Asphalt-concrete surface course	80 (85)	75 (80)	75-85 (80-90)	70-80 (75-85)
	Asphalt-concrete binder course	70 (75)	60 (65)[2]	65-75 (70-80)	70-80 (55-85)
	Sand asphalt	70 (75)	--- (-)	65-75 (70-80)	--- (-)

[1]Figures in parentheses are for use with bulk-impregnated specific gravity (water absorption by aggregate greater than 2.5 percent).

[2]If the inclusion of the optimum asphalt content of these points (average) causes the voids in the total mix to fall outside the limits, adjust the optimum asphalt content so that the voids in the total mix are within the limits.