Using Recycled Glass as Aggregates in Asphaltic Concrete

by

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10779

Dissertation submitted in partial fulfillment of the requirements for the
Bachelor of Engineering (Hons)
(CIVIL ENGINEERING)

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Civil Engineering Programme
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Approved by,

(AP Dr. Madzlan Napiah)

Universiti Teknologi PETRONAS

Tronoh, Perak.

SEPTEMBER 2011

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.

(Mohd Shafuan Azizan)

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Chapter 1: Abstract

The objective of this research study is to compare the performance between normal asphalt concrete and glass asphalt (glassphalt) concrete by finding the optimum bitumen content of each sample. This is to prove the ability of the glass as a replacement to the normal aggregates. Glass cullet, which is processed waste, can be reused as aggregates in order to reduce the depletion of source rocks. However, anti-stripping agent, which is hydrated lime, must be used to avoid the slipping between glasses surface. Sieve analysis had been carried out for both sample to determine the exact portion of coarse aggregates, fine aggregates and filler. For the glassphalt sample, 10% of glass is being used for the test. The size of the glass sample for this research is below 3.35 mm. The Marshall Test then was carried out to determine the optimum bitumen content for the specific samples. It is found out that for the normal sample, the optimum content is 6 % while for glassphalt concrete is 6.5%. The stability of the glassphalt concrete is slightly higher than normal aggregates. This research can be improved in the future by using various sizes of the glass. Glass might not give a great improvement on the stability of the asphaltic concrete, but it will save the environment by giving adequate strengths needed in asphaltic concrete.

Chapter 2: Introduction

2.1 Background of Study

Pavements are an essential part of our life. We use them as roads, runways, parking lots and drive ways. The construction of road is continued to be a major industry in developing countries. Like any other engineered structure, pavements are expected to be adequately strong and durable for their design life. In other to ensure this, road must be designed, constructed, maintained and managed properly.

Pavements can be classified into asphalt and concrete pavements. Pavements consist of different layers, more so in the case of asphalt pavements than concrete ones. From the bottom, these layers are known as the subgrade, subbase, base and binder or surface. The structure of pavements basically made of some components and aggregate is one of them.

With the rapid growth and increasingly consumption, a large amount of waste is generated. Among them, glass gives a significant numbers that gives some opportunities to the researchers in the construction materials field. As we all aware, to construct pavement, millions ton of aggregates need to be obtained from quarry activities. This results to the depletions of the rock source and affect the environment as well. In order to counter this, it is necessary to adopt sustainable practices. Recovery of maximum value from glass is a key component. Furthermore, public awareness of the environmental importance of recycling glass needs to be improved.

2.2 Problem Statement

In normal practice, aggregates are obtained from quarries or river beds. The process of obtaining aggregates consists of blasting or dredging. Generally good quality aggregates can be produced from different types of igneous rocks, which may contain a wide variety of minerals.

Recycled glass, which is discussed earlier can be useful in asphalt pavement has certain engineering properties in a way can be similar or better than normal aggregates. However, in this case we have to study whether the application of glass in asphalt concrete can be effective or not. Some test need to be carried out to prove that recycled glass will improve the behavior of asphalt concrete.

This project is significant to many developing countries which can reduce the numbers quarry activities. For a developing country, highway construction is a major industry and that is why the materials should be obtained from other sources such as glass. Besides that, use of recycled materials can obviously decreased the cost of highway construction as well.

2.3 Objective

1. **To make a comparative performance study between glass-asphalt concrete and normal asphalt concrete**. Both types can be compared using Marshall Test to indicate the stability for each type in its optimum bitumen content.

2. **To improve the cohesion between stone and glass aggregates by introducing anti-stripping agents**. Anti-stripping agent such as hydrated lime can be used to improve the stiffness modulus of glass asphalt concrete.

2.4 Scope of Study

Several scopes of studies had been outlined in order to complete this task. The major scopes are as follows:

1. The grade of aggregates used for this research study is grade CW20.

2. To scope is within the guidelines of Jabatan Kerja Raya for Malaysian Highway.

3. The glass size used is below than 3.35mm.

2.5 The Relevancy of the Project

This project is relevant to the development in the building materials technology as well as to support the environmental sustainability by using recycled glass as aggregates. Glass waste which has continuously increased in developing countries will be a good addition in asphalt concrete making purpose.

Glass also is good in reflecting big amount and intensity of the light reflection derived by experiments on pavements at night. Thus, throughout this research, conditions for less hazardous driving can be practiced.

2.6 Feasibility Studies

The project will start by collecting materials such as books, journals and technical papers specifically recycled glass, asphalt concrete and pavement engineering. The glass was obtained from a recycling facility factory in Penang. Research will be done from time to time as part of getting a better understanding on this issue.

Utilization of Highway Engineering lab will be done in order to come out with the results.

Chapter 3: Literature Review

3.1 Literature on Recycled Glass as Aggregate in Asphaltic Concrete

There are a lot of references from textbooks, handbook, and encyclopedia that are dealing with glass asphalt; recycled glass, glass cullet and pavement engineering topics as well as journals are available in the area of glass asphalt concrete technology. Among the reference books that describes about the glass usage as aggregate in asphalt concrete are the books written by Ravindra K Dhir et al, Mukesh C Limbachiya et al, J. Mencik, Rajib B. Mallick et al and many more. The specific journals that have connection with this topic are the journals written by Mr. Arabani, Shaopeng Wu et al, G. D. Airey et al, Keinesuke Goto et al, and Dr. Hassan L. Jony.

3.1.1 Glass

Glass–asphalt mixture has been used as a way of recycling waste glass since 1960, and it was about 20 years ago that researchers used waste glass cullet in asphalt mixture aggregates. The first use of glass–asphalt was in the pavements of road test sites to evaluate their strength against moisture. The amount and intensity of the light reflection derived by experiments on pavements at night increased with increasing amounts of waste glass used. [5] Reflection of light that is provided by the road will increase the less hazardous driving during at night. The problem is that, the glass particles are very smooth and their silica content is high. Thus, the glass becomes hydrophilic. This will cause the glass to more prone against water susceptibility. However, the cohesion between bitumen and stone aggregates can be easily destroyed because of the smooth surface of the glass particles in certain circumstances and can result in asphalt pavement stripping. Additives, like hydrated lime, are usually used to prevent the harmful phenomenon of glass–asphalt mixtures while retaining their useful characteristics [5]. The glass particles would have a slight coating of bitumen on its surface due to lack of its ability to absorb bitumen. This will result in small fractioning strength in the joint surface area of glass and asphalt particles. Thus, the fractioning strength of glass–asphalt mixtures is less than that of traditional asphalt concretes. This problem can be encountered by adding 1-2% of lime to the mixture. Furthermore, previous investigations had stated that a higher percentage of lime would result in higher flexibility strength. Satisfactory performance of glass– asphalt pavements containing 10–15% glass cullet content by weight of mix occurs in surface coating mixtures. Regarding the size of the cullets, it is recommended that a maximum size of 4.75 can be used as allowable glass particle dimension in pavements. This is by considering the limits and allowable technical properties including safety issues. A recent study by Arabani et al. in 2008 on the dynamic characteristics of asphalt mixtures containing waste glass aggregates and conventional asphalt concrete mixtures showed an increase in the stiffness modulus of glass–asphalt pavements in comparison with conventional asphalt-mix. Three percent of hydrated lime was used as an anti-stripping agent additive, and the results were compared with those of a specimen without antistripping. The stiffness modulus of the glass–asphalt mixtures with hydrated lime showed considerable increase in comparison with other specimens.

Ordinary glass is rigid and brittle and easy to crush to form satisfactory particles for asphalt concrete applications. The broken glass used in asphalt concrete is characterized by [6]:

- Numerous long and flat particles (especially for big broken glass particles). This may cause problems like stripping of the asphalt film from glass particles surfaces, infirm skid resistance, abrasion of tires, too high reflectance etc.

- The surface of broken glass particles is exceeding smooth and the silica content is relative high, making glass particles a hydrophilic acid aggregate. Pavements with glasphalt may then be sensible to water damage (especially when glass particle size is increased or vast dosage).
- The angularity and friction angle afford insufficient transverse stability (at braking or start-up).
- Low asphalt absorption ratio and density may cause bleeding problems.
- Excellent light reflection properties assure safe nighttime driving, but when glass particle size is increased there is a risk of dazzling.
- The asphalt absorption ratio is near upon zero which is unfavorable to the adhesion of the asphalt film to the broken glass particles.

3.2 Summary of Journal

Author/ Year	Title/Summary
Mr. Arabani (2010)	**Effect of glass cullet on the improvement of the dynamic behavior of asphalt concrete** This journal emphasizes on two important properties of the glass asphalt concrete which are stiffness modulus and optimum bitumen content. This research is using Marshall test in order to find the optimum bitumen content by varying the amount of glass cullet in the aggregate. The stiffness modulus is obtained by carrying out the Indirect Tensile Strength Method (ITSM) test. The cohesion between the glass and stone aggregate is increased by addition of hydrated lime.

Shaopeng Wu, Wenfeng Yang & Yongjie Xue (2004)	**Preparation and Properties of Glass-asphalt Concrete** This journal is mainly about the important properties of the glass and its advantage which can be use as aggregate. The approach used are by carrying out Marshall Test, Rutting Test, Residual Stability Test Immersed in Water and Freezing-Thawing Splitting Test, Rutting Test Immersed in Water, Measures to Improve Water Stability of Glasphalt. Outcome of this projects are: 1. Waste glass can be used in asphalt concrete with maximal size of 4.75mm and the optimal replacement ratio of 10%. 2. The performance such as strength index, high temperature stability and water stability achieve the standards. 3. The water stability of glasphalt can be improved by introducing hydrated lime or liquid anti-striping agent. 4. Liquid anti stripping agent is more effective in improving the water stability of glasphalt than hydrated lime.
G.D. Airey, A.C. Collop and N.H. Thom (2004)	**Mechanical Performance of Asphalt Mixtures Incorporating Slag and Glass Secondary Aggregates** Two asphalt mixture types (gradations) were selected to investigate the performance of glass cullet and slag (BOS and BFS) secondary aggregates in modified bituminous mixtures: 1. mm size dense base asphalt mixture (DBM) as

	specified in BS 4987-1:2001, using a 50 penetration grade bitumen; 2. mm stone mastic asphalt (SMA) wearing course asphalt mixture as specified in prEN 131018-5:2000, using a 50 penetration grade bitumen and cellulose fibres. The two asphalt mixtures were selected to represent a typical UK base and wearing course (surfacing) material. The following primary and secondary aggregates, in various combinations, were used to produce the above asphalt mixtures: • Gritstone aggregate (Bayston Hill) with a SG of 2.76; • Limestone aggregate (Ballidon) with a SG of 2.7; • Limestone filler (Ballidon) with a SG of 2.7; • Steel slag (Llanwern) with a SG range of 3.0 to 3.27; • Blast furnace slag (Port Talbot) with a SG range of 2.36 to 2.47; • Glass cullet with a SG of 2.5.
Keinosuke Gotoh, Minoru Yamanaka, Motoki Saruwatari, and Teruo Mochishita (2001)	**Thermal and Mechanical Properties of Glass Cullet Mixed with Asphalt as Low-Exothermic Pavement Material** This journal mainly about the thermal and mechanical properties of glass cullet mixed with asphalt by the following test: 1. Measuring surface temperature by using Thermal Video Camera. This is to check on glass cullet radiation temperature of the specimens. It is carried

	out in 4 days for 10 minutes. 2. CBR test to check the strength of the specimens. From this paper, it can be concluded that cullet has the ability to reduce the surface temperature when mixed with asphalt. Besides that, the adhesion of the asphalt decreased with the increased of cullet amount.
Dr. Hassan H. Jony, Mays F. Al-Rubaie, and Israa Y. Jahad. (2010)	**The Effect of Using Glass Powder Filler on Hot Asphalt Concrete Mixtures Properties** The main study considered in this paper is to investigate the effect of using glass powder filler on hot asphalt concrete mixture properties where the results can be concluded as the following: 1. A satisfactory stability is indicated, where using glass powder filler improve the Marshall stability values for all mixtures comparing to Portland cement or limestone powder fillers. The percentage of increase ranging from 6% to 36% depending on percentage of filler. 2. The average value of Marshall flow is less than resulted from mixtures with ordinary Portland cement or limestone powder fillers. 3. Using glass powder filler in hot asphalt concrete mixtures led to produce lighter mixtures almost with higher percentage of voids as compared with corresponding mixtures containing ordinary

	Portland cement or limestone powder. The maximum reduction is 15% achieved at 10 % replacement as compared with corresponding ordinary Portland cement mixture.

Chapter 4: Materials and Methodology

4.1 Materials

4.1.1 Glass

In this study, the glass that is used is obtained from a recycling factory in Penang. The glass's size ranged below than 4.75 mm to avoid skin cutting hazard. For this research, 10% of glass is used for each sample.

4.1.2 Aggregates

The aggregates used for this research is taken from the highway laboratory with gradation limits by Jabatan Kerja Raya for HMA. The grade used is CW20. The gradation is shown in Table 1.

JKR Specification – Gradation of Aggregates	
Sieve Size (mm)	% by Weight Passing
28.0	100
20.0	76-100
14.0	64-89
10.0	56-81
5.0	46-71
3.35	32-58
2.35	20-42
0.15	12-28
0.075	6-16
Filler	4-8

Table 1: JKR Specification

4.1.3 Hydrated lime

In this study, 4% of hydrated lime is used for glass aggregates to increase the cohesion between the aggregates due to the smooth surface of the glass. The cohesion between bitumen and stone aggregates can be easily destroyed because of the smooth surface of the glass particles in certain circumstances and can result in asphalt pavement stripping. Additives, like hydrated lime, are usually used to prevent the harmful phenomenon of glass-asphalt mixtures while retaining their useful characteristics.

4.2 Research Methodology

Research methodology for this project is divided into two parts:

a) Stability study of normal design mix asphaltic concrete.
b) Stability study of glass asphaltic concrete.

4.2.1 Performance study of normal design mix asphaltic concrete

Procedure

a) Sieve analysis need to be conducted to determine the grain distribution of the aggregates.
b) Graph of the grain distribution is plotted.
c) From that, the percentage of each aggregate can be obtained.
d) Mass of each aggregate can be computed in order to prepare 21 samples of 1200gram each for the Marshall test. 3 samples for each of 5.0, 5.5, 6.0, 6.5, 7.0, 7.5, 8.0 percentage of bitumen content from the mix weight are used for this test.
e) Samples are weighed in air and in water to obtain the density.
f) Dimension of each sample were taken.
g) Flow and Stability graph is plotted.
h) From the graph, optimum bitumen content is analyzed.

4.2.2 Performance study of glass asphaltic concrete

Procedure

a) Sieving analysis need to be conducted to determine the grain distribution of the aggregates. In this part 10% of total mass is replaced by glass cullet sized below than 3.35 mm.
b) Graph of the grain distribution is plotted.
c) From that, the percentage of each aggregate can be obtained.
d) Mass of each aggregate can be computed in order to prepare 21 samples of 1200gram each for the Marshall test. 3 samples for each of 5.0, 5.5, 6.0, 6.5, 7.0, 7.5, 8.0percentage of bitumen content from the mix weight are used for this test. Bear in mind that this sample has to be added with 4% of hydrated lime.
e) Samples are weighed in air and in water to obtain the density.
f) Dimension of each sample were taken.
g) Flow and Stability graph is plotted.
h) From the graph, optimum bitumen content is analyzed.

4.3 Project Activities

This project involves several laboratory test related to asphalt concrete. Specifically, it is a study of recycled glass as the alternative for natural aggregate in asphaltic concrete. First and foremost, the project will begin with the research on several issues on the glass engineering properties. The project then is continued by obtaining the gradation size of the particles. A total of 42 samples were prepared. Marshall Test is conducted and the result is plotted in graph for the interpretation.

4.4 Tools and Apparatus

These are the tools that are going to be used throughout this project.

1. Basic Marshall Test set
2. Mixer
3. Sieving machine
4. Personal Protective Equipment (PPE)

4.5 Key Milestone and Gantt chart

Final Year 3rd Semester (Sept 2011)																	
No.	Detail/Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14	15
1	Mixing for control sample	■	■	■	■												
2	Marshall Test					■											
5	Mixing for glass asphaltic concrete sample						■	■		■							
6	Submission of Progress Report									■							
7	Marshall Test										■	■					
10	Poster Presentation												■				
11	Submission of Draft Report													■			
12	Submission of Dissertation														■		
13	Submission of Technical Paper														■		
14	Oral Presentation															■	
15	Submission of Project Dissertation (Hard bound)																■

Table 2: Gantt chart

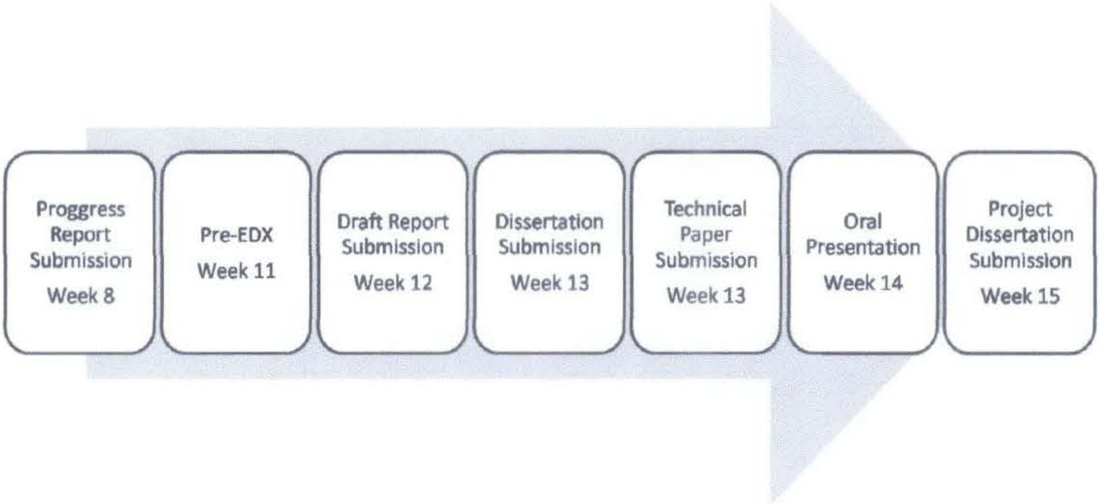

Figure 1: Key Milestone

Figure 2: Obtaining the result for Marshall Test

Figure 3: Mixing process

Figure 4: Samples of asphalt concrete

Chapter 5: Result and Discussion

5.1 Experimentation

The experiment was first being conducted to obtain the particle size distribution of the sample. Sieves size of 0.075, 0.15, 2.35, 3.35, 5, 10, 14, 20 and 28 mm are used for this analysis. The research then is continued for Marshall Test by varying the bitumen content of 5.0%, 5.5%, 6%, 6.5%, 7.0%, 7.5% and 8.0%. The mix then was compacted with Marshall Compactor with 75 blows. When the sample got its shape, it was left in a room temperature for 24 hours. After that, the sample had to be sunk in a hot bath with a temperature of 60 ^{o}C for 30 minutes. The sample then was placed in the Marshall equipment to run the test. **Note:** The equipment needs to be properly calibrated before running the test so that the sample will not be wasted.

The result was recorded and plotted on a graph.

5.1.1 Sieve Analysis

In this project study, dry sieving method is used to determine the particle size distribution of soil. The result is divided into two parts, with and without glass. The sieving result are shown in Table 3 and illustrated in Figure 5.

Normal Asphalt – Size Distribution	
Sieve Size (mm)	% by Weight Passing
28.0	100
20.0	98.69
14.0	71.56
10.0	59.59
5.0	57.32
3.35	57.00
2.35	44.52
0.15	9.97
0.075	6.00
Filler	-

Table 3: Size Distribution

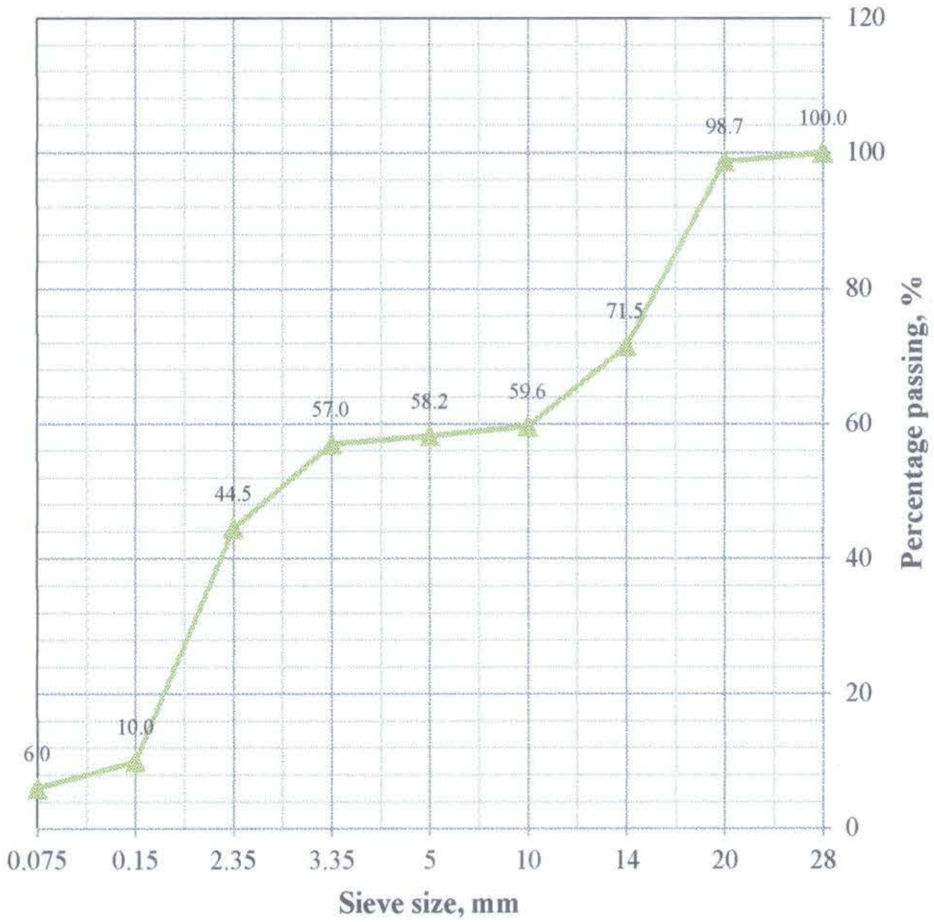

Figure 5: Particle Size Distribution

Based on the Particle Size Distribution diagram, the aggregates can be classified as gap-graded. That means, there is big difference in terms of size. It is observed that sieves sized 0.15mm and 14mm retained the most of the aggregates. Although this kind of grading can be classified as costly, but it did cause the outer surface of the concrete become smoother. The aggregate stays within the gradation of CW20 Jabatan Kerja Raya limit of Hot Mix Asphalt. Based on the sieve analysis, it was found out that for the normal asphalt concrete, the samples contained (% of total weight):

Coarse aggregate : 42.60 %

Fine aggregate : 50.10 %

Filler : 7.30 %

For glass asphalt concrete samples, sieve analysis was done on the glass cullet. For this research the glass size distribution is tabulated in the Table 4.

Glass – Size Distribution	
Sieve Size (mm)	% by Weight Passing
3.35	100
2.35	90.12
0.15	79.23
0.075	26.99
Filler	-

Table 4: Glass size distribution

From the table, it can be concluded that, most of the particles can be described as fine grain. This is because, it is stated earlier that, the particles of glass have the limit of 4.75mm for safety purposes. Thus, all of the glass passed the 3.35mm sieve. Most of the glass retained on 0.075mm sieve. It was predicted that, the gradation will different with the normal aggregates in terms of fine grain portion. This sample was taken from a recycling factory in Penang after processed. The color of the glass itself is white. Same procedure has to be made with other aggregate. It was dried in the oven for 24 hours to remove water.

The glass then was combined with the normal aggregates because glass could only replace on certain portion of aggregates. This is important, so that the sample has correct portion of aggregates. Based on analysis, the percentage of coarse aggregates, fine aggregates, and filler were obtained. The results are:

Coarse aggregate : 47 %

Fine aggregate : 35 %

Filler : 8 %

Glass aggregate : 10%

The combined size distribution is shown in Figure 6:

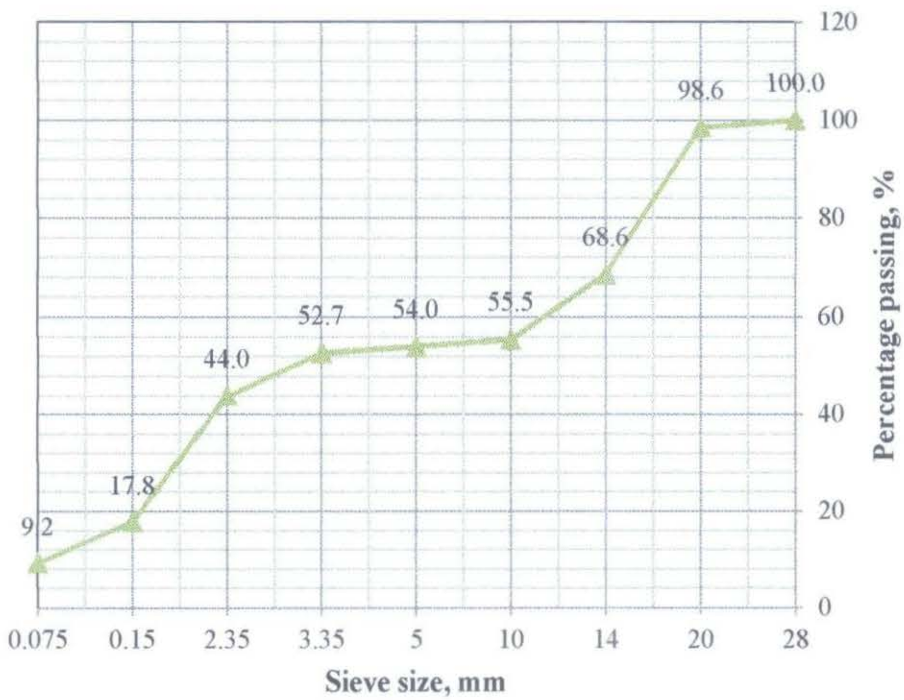

Figure 6: Particle Size Distribution (Glass)

Based on the Particle Size Distribution diagram, the aggregates can be classified as gap-graded. That means, there is big difference in terms of size. It is observed that sieves sized 0.15mm and 14mm retained the most of the aggregates. This is same compared to the normal aggregates distribution, but the value of the retained is different. There is not much increment between sieves of 3.35, 5.0, and 10mm. This is due to the gap-graded gradation of the particles. However, same as the normal aggregates, the aggregate stays within the gradation of CW20 Jabatan Kerja Raya limit of Hot Mix Asphalt.

5.1.2 Marshall Test

Marshall Test was carried out for both test to obtain the stability and flow for each sample. From that data, a graph was plotted to indicate the optimum bitumen content of each mix. A total of 21 samples were prepared with 5%, 5.5%, 6%, 6.5%, 7%, 7.5% and 8% bitumen content (3 samples each). Table 5, Figure 7 and Figure 7 illustrate the result for normal aggregates concrete:

Marshall Test		
Bitumen Content (%)	Stability (kN)	Flow (mm)
5.0	3.51	2.43
5.5	6.33	2.25
6.0	9.28	2.19
6.5	7.05	2.00
7.0	5.05	2.22
7.5	4.77	2.75
8.0	4.30	3.07

Table 5: Marshall Test

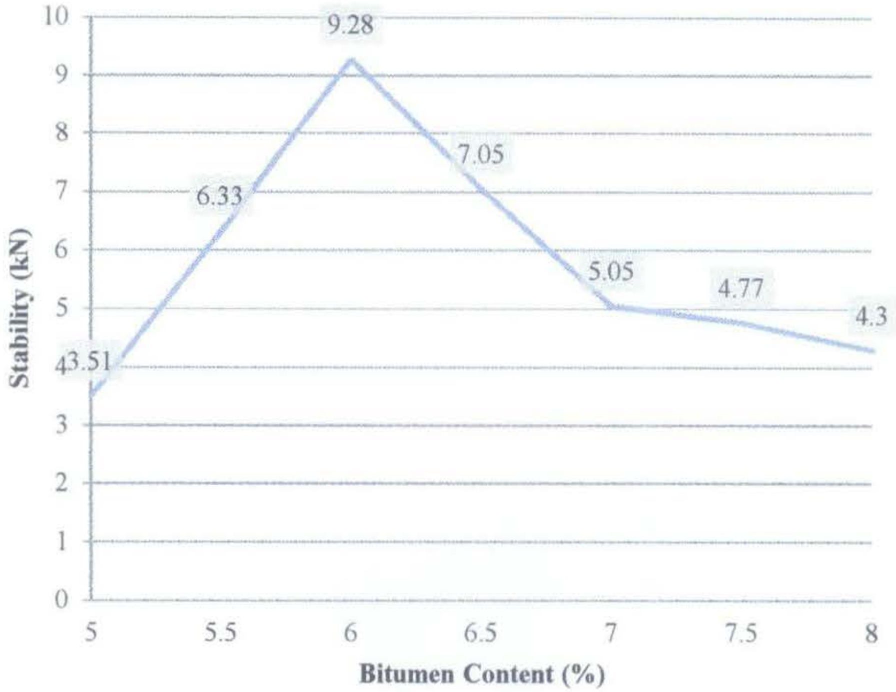

Figure 7: Bitumen Content vs. Stability

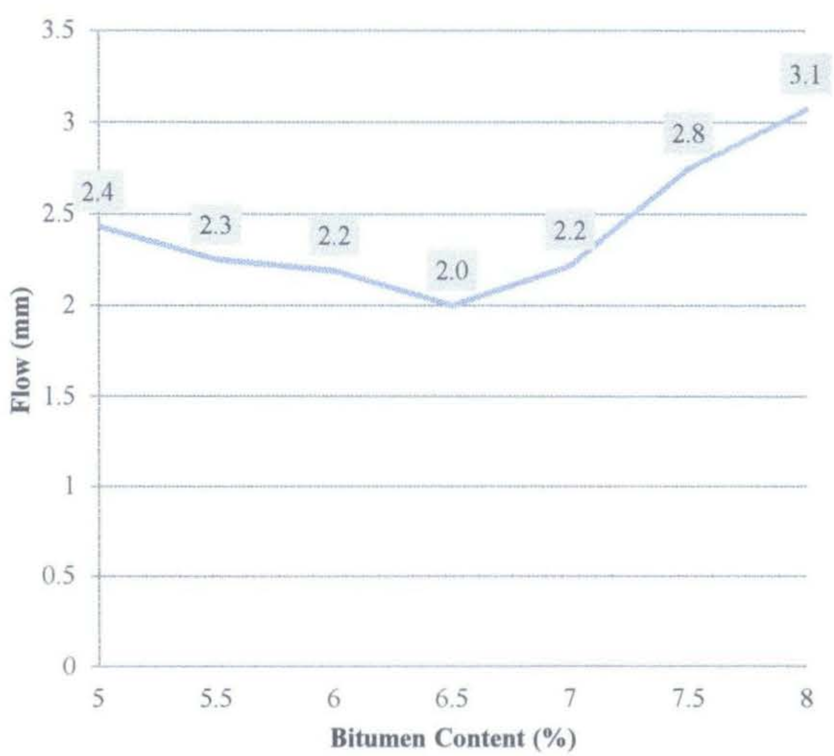

Figure 8: Bitumen Content vs. Flow

For the stability of the normal aggregate mix, the value increase from 3.51 to 9.28 for 5-6% of bitumen content. However, it began to decrease to 7.05 continuously until 4.3 with 6.5 to 8 % of bitumen content. Therefore, the optimum bitumen content for this sample is 6% which is 9.28 kN. At 6%, normal aggregate sample has the highest in terms of its stability. This is due to, at this point, the bitumen had given sufficient bonding to keep the grain interlocking with each other.

For the flow graph, it is observed that, the flow is reduced from 2.4 to 2.0 for the bitumen content of 5 to 6.5. This is because of the bitumen keeps preventing the aggregates from slip with each other. However, the flow keeps reducing for the remaining values of the bitumen. The sample tends to lose its strength again due to more prone to slip with each other. The flow of the 6% of bitumen content was recorded as 2.2 which lie within the JKR limit of flow. The allowable flow is between 2-4 mm.

For glass asphalt aggregates, all together, a total of 21 samples were prepared with 5%, 5.5%, 6%, 6.5%, 7%, 7.5% and 8% bitumen content (3 samples each). Table 6, Figure 9 and Figure 10 illustrate the result for glass aggregates concrete:

	Marshall Test	
Bitumen Content (%)	Stability (kN)	Flow (mm)
5.0	3.88	1.91
5.5	5.63	2.35
6.0	7.20	2.27
6.5	10.51	3.13
7.0	7.47	3.40
7.5	6.53	3.86
8.0	3.54	5.14

Table 6: Marshall Test (Glass)

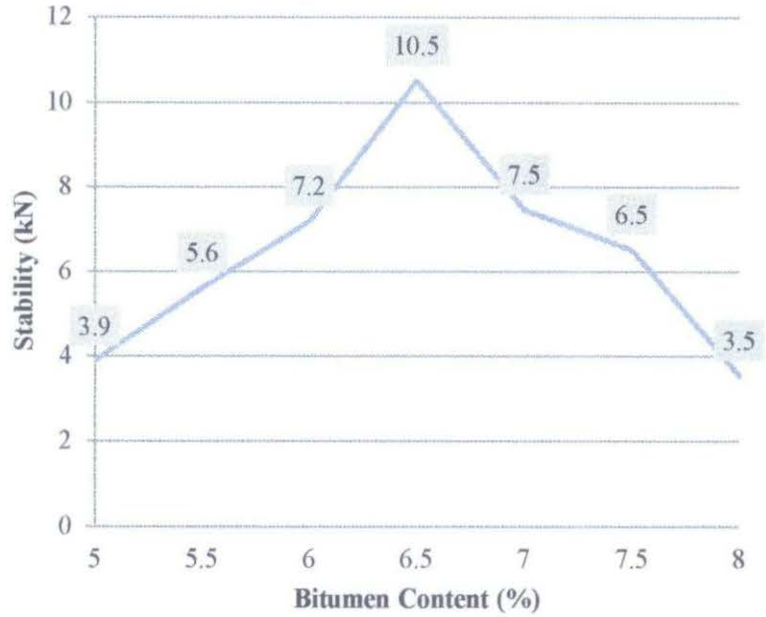

Figure 9: Bitumen Content vs. Stability (Glass)

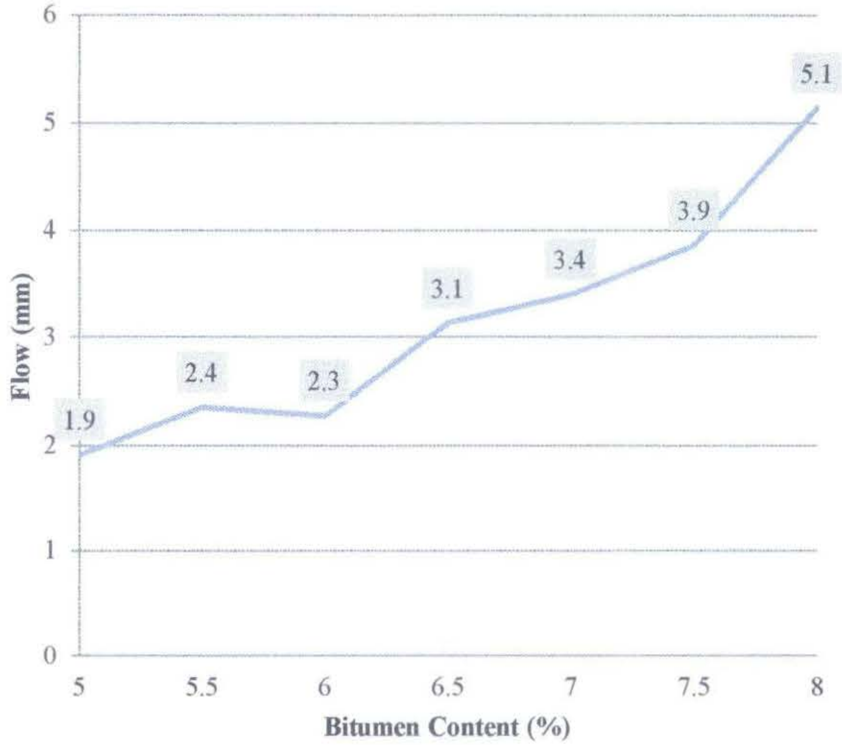

Figure 10: Bitumen Content vs. Flow (Glass)

For the stability of the normal aggregate mix, the value increase from 3.9 to 10.5 for 5 to 6.5% of bitumen content. However, it began to decrease to 7.5 continuously until 3.5 with 7 to 8 % of bitumen content. Therefore, the optimum bitumen content for this sample is 6.5 % which is 10.51 kN. At 6%, normal aggregate sample has the highest in terms of its stability. This is due to, at this point, the bitumen had given sufficient bonding to keep the grain interlocking with each other.

For the flow graph, it is observed that, the flow is increasing from 1.9 to 2.4 and it is decreased to 2.3mm. Again, the flow keeps increasing until 5.1mm. This result indicates that, glass has more prone to each other due to its smooth surface. This however is still within the limit of flow by JKR. The flow of the 6% of bitumen content was recorded as 2.2 which lie within the JKR limit of flow. The allowable flow is between 2-4 mm.

It is said earlier that glass particles would have a slight coating of bitumen on its surface due to lack of its ability to absorb bitumen. This will result in small fractioning strength in the joint surface area of glass and asphalt particles. Thus, the fractioning strength of glass–asphalt mixtures is less than that of traditional asphalt concretes. However, this matter is already been encountered by the addition of 4% of hydrated lime. Hydrated lime gives the glass better flexibility.

Hydrated lime also did improve the cohesion between bitumen and stone aggregates. It is also stated earlier the cohesion between them can be easily destroyed because of the smooth surface of the glass particles in certain circumstances and can result in asphalt pavement stripping.

The flow of the 6.5 % of bitumen content was recorded as 3.13 which lie within the JKR limit of flow. The allowable flow is between 2-4 mm. The result can be summarized as follows:

Summary			
Aggregate Type	OBC (%)	Stability (kN)	Flow (mm)
Normal	6.0	9.28	2.19
Glass	6.5	10.51	3.13

Table 7: Summary of Results

The result has shown that, the stability of 10.51 kN is observed for the glass aggregates compared to the normal aggregates. However, the addition of 0.5% of bitumen compared to normal aggregates is needed in order to reach that stability. The difference in stability shows that, glass, has better cohesion between the aggregates compared to normal aggregates. This is also by the addition of hydrated lime which increases the cohesion of the aggregates. On the other hand, the addition of hydrated lime also assisted in encountering the problem of smaller fractioning strength compared to the normal aggregates. The higher value of optimum bitumen content is because of the size distribution itself. The glass requires more bitumen for it to bind with other aggregates. Furthermore, coarse aggregates are greater amount in glass asphaltic concrete sample. Thus, more bitumen is needed.

Chapter 6: Conclusion and Recommendations

6.1 Conclusion

In a conclusion, this project is a comprehensive research study about the usage of recycled glass as aggregate in asphaltic concrete. The project is the study of the properties of glass and its ability to enhance the performance of aggregate in asphalt concrete. This project is using the approach of investigating the strength of the concrete. At the end of this research, we are able to compare the performance between glass asphaltic concrete and normal asphaltic concrete. With this project, the technology of making asphalt concrete has improved in terms of its sustainability towards environment. The rate of quarry activities can be reduced while increasing the development. The glass has revealed its ability in replacing normal aggregates by presenting its stability in the mix. The result has shown that, the stability of 10.51 kN is observed for the glass aggregates compared to the normal aggregates. However, the addition of 0.5% of bitumen compared to normal aggregates is needed in order to reach that stability. The difference in stability shows that, glass, has better cohesion between the aggregates compared to normal aggregates. This is also by the addition of hydrated lime which increases the cohesion of the aggregates. The higher value of optimum bitumen content is because of the size distribution itself. The glass requires more bitumen for it to bind with other aggregates. Furthermore, coarse aggregates are greater amount in glass asphaltic concrete sample. Thus, more bitumen is needed. The usage of glass however, increased slightly in terms of the stability of the asphaltic concrete. But, it is important to note that, to reach the adequate stability, 10% amount of source rocks can be actually saved by using this technology. However, this amount needs to be replaced by additional of 0.5% of bitumen. For this approach, contractor/client has to review how this additional of 0.5% bitumen gives impact towards the environment and the overall cost of the project. In terms of practicality, in Malaysia, we have several sources for glass cullet supply. There is *LHT Kitarsemula Sdn. Bhd.* in Penang and while *PUM Cullet Sdn. Bhd.* in south of Malaysia.

6.2 Recommendations

The material used in this project is glass which is widely used as a foods and drinks container, windows, houses, transports, and ornaments. This material then is disposed, treated and recycled for further use. The recycling business should expand in a way it can support enough glass for the use of nation's development. Thus, the recycling facility should be bigger so that the amount of glass cullet produced is sufficient. The project owner also has to view the usage of this material as an economical and efficient one. The university should encourage their students to find alternatives in construction material which will experience depletion if no action has been taken. Regardless the results of present study, some improvement in this area can be done such as using various sizes for the glass cullet. This might improve the stability of the glass asphaltic concrete due to the better distribution of the glass size. Bear in mind that, by using the result on this study, further research can be carried out to find out more comparison between both samples. Some tests that can be conducted are Creep Test Analysis and Wheel Tracking Test. Since the glass is hydrophilic material and has high silica content, glass is more prone to water damage. Thus, some test can be carried out to determine its water susceptibility. This application also may be applied to surface course rather than to focus on the base course itself. The reflection from the glass will help the road users' vision and this promotes better condition of highway during the night.

Chapter 7: References

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Appendices

Appendix I

Finding the OBC value of glass asphalt concrete

Bitumen content	Height	Mass of Specimen		Specific Gravity		Void	Stability	Flow
		In Air (g)	In Water (g)	Bulk	Theory			
5	74.77	1200.4	626.4	2.09	2.25	7.05	3.8	1.91
5.5	73.61	1214.3	636.3	2.10	2.2	4.51	5.63	2.35
6	72.23	1256.7	688.3	2.21	2.29	3.45	7.2	2.27
6.5	72.43	1267.6	707.3	2.26	2.34	3.32	10.51	3.43
7	71.67	1273.9	704	2.24	2.3	2.81	7.47	3.4
7.5	70.57	1288.4	710	2.23	2.27	1.87	6.53	3.86
8	70.32	1275.3	700	2.22	2.25	1.48	3.54	5.14

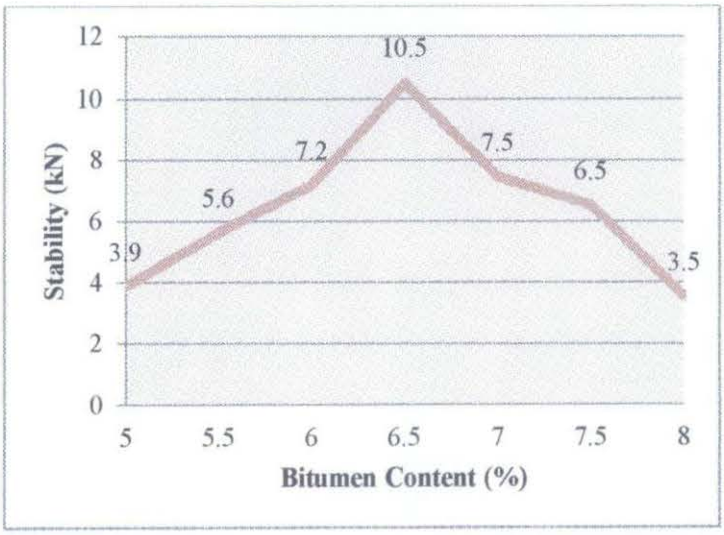

Figure 11: Bitumen Content vs Stability

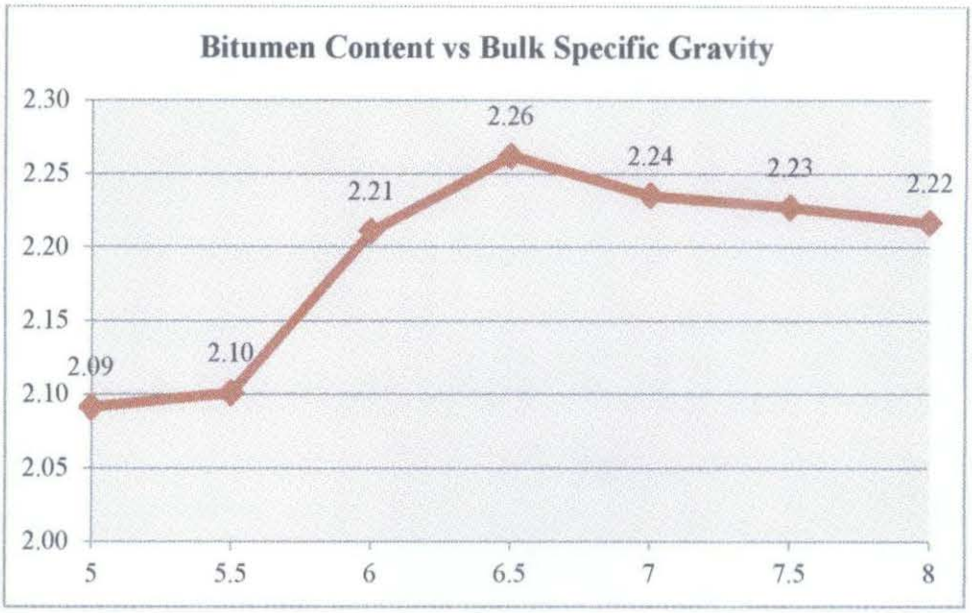

Figure 12:Bitumen Content vs Bulk Specific Gravity

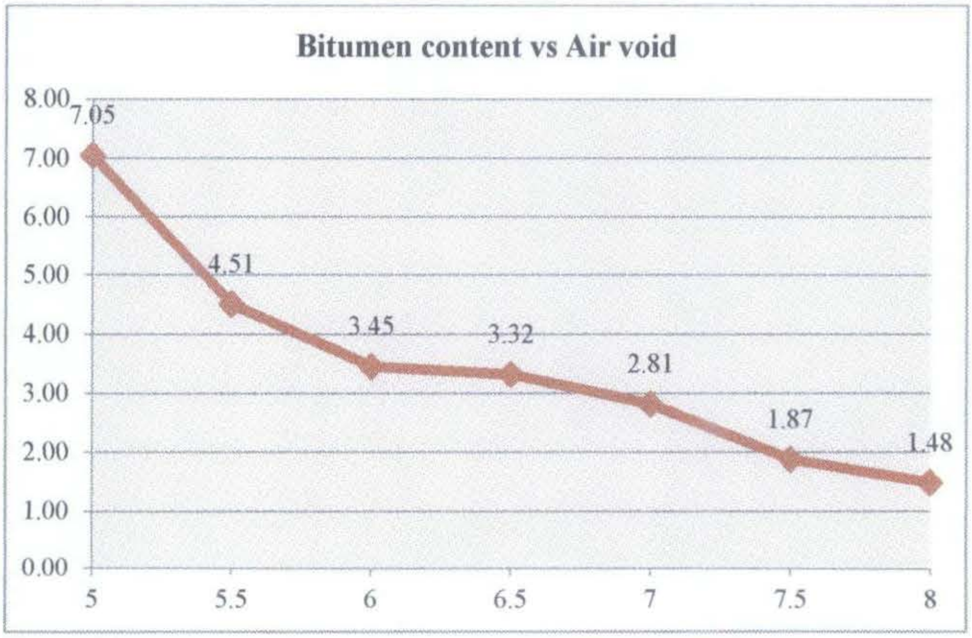

Figure 13: Bitumen content vs Air Void

Thus, the optimum bitumen content for glass asphalt concrete is: **(6.5 + 6.5 +6)/3 = 6.33%**

THE END