The Usage of Copper Slag in Bituminous Mix

by

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CERTIFICATION OF APPROVAL

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Approved by,

(AP Dr. Madzlan Napiah)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

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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.

MOHD. AMIRUL FAREZ BIN AHMAD AZALDIN

ABSTRACT

This report basically discusses the researches done and basic understanding of the chosen topic, which is '**The Usage of Copper Slag in Bituminous Mix'.** Copper slag is produced as waste from roasting of copper, in which sulphur (as SO^2) is eliminated. Disposal of many million tons of wastes such as copper slag is responsible for health hazards and degradation of environment. The purpose of the research is to determine the performance of the asphalt pavement with the existence of copper slag, compared with the conventional asphalt pavement. The use of copper slag, in hot bituminous mixes is to enhance the pavement performance, to protect the environment and to provide low cost roads is the need of hour. There have been researches done where copper slag was used as fine aggregate (up to 30%) or filler in the design of bituminous mixes like Bituminous Macadam, Dense Bituminous Macadam, Bituminous Concrete and Semi-Dense Bituminous Concrete. The addition of copper slag in various bituminous mixes provides good interlocking and eventually improves volumetric and mechanical properties of bituminous mixes. The research is conducted by adding the copper slag to substitute the filler in the asphalt mixtures while finding the optimum mix. The mixes are made to comply with the standards of the pavements done in the industry set by Jabatan Kerja Raya (JKR) and Projek Lebuhraya Utara-Selatan (PLUS). Tests are done on the aggregates used for the mix and also on the hot mix asphalt and based on the result it is found that copper slag can replace the use of cement in bituminous mix while also increase the quality of the pavement.

ACKNOWLEDGEMENT

All praise be to Almighty God, Lord of the worlds, who, through His mercy and grace, has revealed some of His knowledge to me in the course of this project. Verily all good are from Him and all shortcomings are due to my own weaknesses.

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ABBREVIATIONS AND NOMENCLATURES

MgO	-	Magnesium Oxide
Al_2O_3	-	Alumina Trioxide
SiO_2	-	Silicon Dioxide
SO_3	-	Sulfur Trioxide
K_2O	-	Potassium Dioxide
CaO	-	Calcium Oxide
TiO_2	-	Titanium Dioxide
Cr_2O_3	-	Chromium Trioxide
MnO	-	Manganese Oxide
Fe_2O_3	-	Ferric Oxide
CuO	-	Copper Oxide
ZnO	-	Zinc Oxide
As_2O_3	-	Arsenic Trioxide
SrO	-	Strontium Oxide
ZrO_2	-	Zirconium Dioxide
MoO_3	-	Molybdic Trioxide
Tb_4O_7	-	Terbium Oxide
Re	-	Rhenium
Os	-	Osmium
PbO	-	Lead Oxide

CHAPTER 1
INTRODUCTION

1.1 BACKGROUND STUDIES

Highway pavements are divided into two main categories: rigid and flexible. The wearing surface of a rigid pavement is usually constructed of Portland cement concrete such that it acts like a beam over any irregularities in the underlying supporting material. The wearing surface of flexible pavements, on the other hand, is usually constructed of bituminous materials such that they remain in contact with the underlying material even when minor irregularities occur. Flexible pavements usually consist of a bituminous surface underlaid with a layer of granular material and a layer of a suitable mixture of coarse and fine materials. Figure 1.1 shows how the traffic loads are transferred by the wearing surface to the underlying supporting materials through the interlocking of aggregates, the frictional effect of the granular materials, and the cohesion of the fine materials.

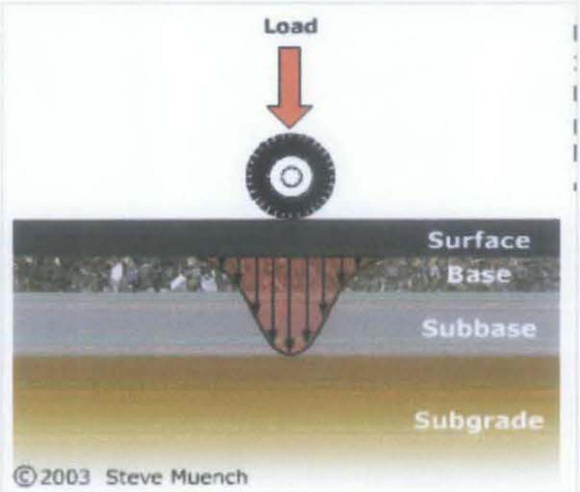

Figure 1.1: Flexible Pavement Load Distribution

(Source: http://pavementinteractive.org)

The research is conducted to determine the suitability of copper slag to be incorporated in bituminous mix to replace completely the whole of filler during mixing and finding the best design mix using method such as the Marshall Mix Design. Usually, the filler for the bituminous mix consists of cement from Ordinary Portland Cement (OPC) or limestone. It is hoped that copper slag addition will present greater mechanical and durability performance towards the pavement. Other materials used for mixing are fine aggregates, coarse aggregates and binder.

The use of copper slag in highway construction as an aggregate is economically viable. Its most promising application is as filler in asphalt pavements. Concerns were expressed about its use from an environmental viewpoint but if proper handle and care is practice, that would not be a problem. The use of industrial solid waste to bituminous production is environmentally friendly because it contributes to reducing the consumption of natural resources, the pollution the production generates and the power it consumes while also reducing the space the waste occupies because in general, the whole world is generating millions of tons of slag each year. Figure 1.2 shows the copper slag being piled inside the Malaysia Marine and Heavy Engineering (MMHE), located at Pasir Gudang in Johor. Copper slag samples used were taken from MMHE.

Figure 1.2: Copper Slag in MMHE

1.2 PROBLEM STATEMENT

In Malaysia, two types of pavements are commonly used in road construction, flexible pavement and rigid pavement. However, majority of the roads are constructed using the flexible pavements. A flexible pavement is a layered structure consisting of a subbase course, base course, binder course and wearing course (Figure 1.3). Generally, most of the flexible pavements deteriorate faster than rigid pavement, which in turn requires more maintenance to the flexible pavement roads. They are classified as "flexible" pavements because the total pavement structure deflects, or flexes, under loading.

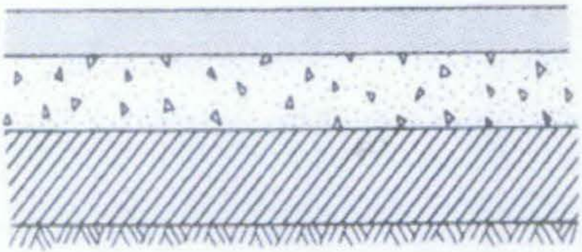

Figure 1.3: Schematic of a Flexible Pavement

(Source: Nicholas, J. G. and Lester, *A. H., 2002, Traffic & Highway Engineering)*

The deterioration of flexible pavement arises from deformation under traffic loading, generally associated, in the later stages, with cracking (Figure 1.4) and rutting (Figure 1.5).

Figure 1.4: Cracking Pavement

Figure 1.5: Rutting Pavement

(Source: http://www.tfhrc.gov/)

Cracking is series of interconnected cracks caused by fatigue failure after repeated loading while rutting is surface depression in the wheel path caused by permanent deformation under traffic load.

This research hopes to produce better performance asphalt pavement with the copper slag being incorporated into the mix while also help reducing the problem of waste management without polluting the environment and contributes a new technology in highway engineering.

1.3 OBJECTIVE & SCOPE OF STUDY

The main objective of the project is to study the effects of copper slag as a substitute of filler in flexible pavements. The laboratory tests that are conducted during and after mixing were sieve analysis, Marshall Mix Design, Wheel Tracking Test, Beam Fatigue Test and also Creep Test. For the copper slag, XRD/XRF Test are conducted to find the material's composition.

The Marshall Method for hot-mix asphalt concrete mix design is a rational approach to selecting and proportioning two materials, asphalt cement and mineral aggregates to obtain the specified properties in the finished asphalt concrete surfacing structure. The method is intended for laboratory design of asphalt hot-mix paving mixtures. Marshall Mix Design is also conducted to obtain the optimum binder content conformed to Jabatan Kerja Raya (JKR) and Projek Lebuhraya Utara-Selatan (PLUS) standard. Besides that, the behaviour of the mix also need to be analyzed for its stability, flow, bulk density and porosity.

The Marshall stability is the maximum load the specimen can withstand before failure when tested in the Marshall Stability test. The configuration of the Marshall Stability test is close to that of the indirect tensile strength test, except for the confinement of the Marshall specimen imposed by the Marshall testing head. Thus, the Marshall stability is related to the tensile strength of the asphalt mixture.

Meanwhile, the Marshall flow is the total vertical deformation of the specimen, when it is loaded to the maximum load in the Marshall Stability test. The Marshall flow can provide sonic indication of the resistance of an asphalt mixture to plastic deformation. Mixtures with low flow numbers are stiff and may be difficult to compact. However, these mixtures are more resistant to rutting than those with high flow numbers. Mixtures with flow numbers above the normal range may be "tender mixes," which are susceptible to permanent deformation.

Wheel Tracking Test is to study whether the existence of copper slag in asphaltic concrete pavement can reduce the indenting effect when induced with repeated loading under the temperature of 45°C, stimulating the temperature at field. Apart from that, this test also can study the tear off effect of bitumen from aggregate surface.

Beam Fatigue Test is one of the typical ways of estimating the pavement's fatigue properties. The flexural test determines the fatigue life of a small asphaltic beam specimen (380 mm long x 63 mm wide x 50 mm thick) by subjecting it to repeated flexural bending until failure. The beam specimen is sawed from either laboratory or field compacted asphaltic pavement.

This project will compare the performance of conventional Asphaltic Concrete Wearing Course (ACWC) 20 that are widely use in the industry with the mix that is using copper slag as filler based on results gain in several laboratory testing mentioned above.

CHAPTER 2
LITERATURE REVIEW

2.1 INTRODUCTION

In recent years, technological progress, industrial development, population growth, and the resulting increase in consumption of natural resources have caused a disorderly use of nonrenewable resources, increased power consumption, as well as the generation of large volumes of urban and industrial waste. Consequently, negative environmental impacts such as the depletion of the ozone layer, the greenhouse effect, and water spring pollution are increasingly harming the humankind. The construction activity causes great damage to the environment due to the consumption of large volumes of natural resources and power and by the large volumes of waste it generates. However, this industry is also characterized by a high potential to use recycled waste in construction materials. Thus, many research activities have been carried out with the purpose of using waste as a supplementary cementing material for the production of cement-based materials to be used in the industry. (Amit et al., 2007)

Solid waste management has become a major environmental issue, which seeks to minimize the health, environmental and aesthetic impacts of solid waste. Disposal of many million tons of non-decaying plastics waste and copper slag is responsible for health hazards and degradation of environment. The use of waste plastics and copper slag, in hot bituminous mixes to enhance the pavement performance, to protect the environment and to provide low cost roads is the need of hour.

According to Washington, Jardel and Monica

> "Copper production activities result in significant amounts of slag during the process for transforming raw material into finished goods. Nearly 13 million tons are generated worldwide. An average of 230 thousand tons is generated annually in

Brazil, which needs too much landfill space for storing the copper slag. Using copper slag as raw material in the construction industry appears to be an alternative to minimize this problem." (Washington et al., 2007)

Used copper slag is the largest source of waste from shipyards and refineries. Even for our neighbouring country, Singapore, "each year, some 300,000 tonnes are used for abrasive blasting at shipyards, during which the copper slag grit breaks into smaller particles that are contaminated or mixed with rust and paint. Although a non-toxic waste, used copper slag would pose a problem to land-scarce Singapore, which has limited authorised dumping grounds. The Ministry of Environment had since levied a charge of $67 for every tonne of waste dumped at its landfills." (Sembcorp Marine, 2000)

Pundhir, in his paper entitled "Use of waste plastics and copper slag (CS) for low cost bituminous roads," stated that the physical properties of waste plastic modified bitumen (WPMB) were found within specified limits when using copper slag as a substituting material. Using 60/70 and 80/100 bitumen, waste plastic modified bitumen was prepared in laboratory and quartzite aggregate, stone dust, lime and copper slag (10, 15 and 20 %) were mixed to prepare Marshall specimens. The Marshall specimens were tested for density, stability, flow, retained stability and indirect tensile strength. 15 % copper slag showed the best in three variables. So more variations on the percentage of the copper slag will be used and the same applies for the bitumen. (Pundhir et al., 2005)

There has been limited use of copper slag aggregates in hot mix asphalt pavements. Copper oxide blasting grit (fine copper slag) has reportedly been used in hot mix asphalt pavements in California, and granulated copper slag has reportedly been incorporated into asphalt mixes in Georgia to improve stability. Although it is rarely used, Michigan Department of Transportation specifications consider reverberatory copper slag to be a conventional coarse and fine aggregate for hot mix asphalt pavements. (Reuter et al., 2004)

Permanent deformations, primarily in the form of ruts, are one of the basic asphalt pavement damages impairing its service properties. Application of appropriate asphalt mixtures and binder modification are effective methods for improving asphalt courses resistance. While being manufactured, stored, fitted into a road pavement and during long term service, bitumen binders and asphalt mixtures are subject to continuous unfavourable ageing processes during which pavement courses characteristics change considerably, resistance to permanent deformations being among them. (Radziszewski, 2007)

2.2 MATERIALS CLASSIFICATION

The materials used for construction can be classified under several groups namely:

- Coarse aggregates
- Fine aggregates
- Filler
- Binder

The classification of materials is important to ease the process of selecting the suitable materials for the asphaltic concrete mix. This is because the structure component within the pavement will determine the traffic loading that the pavement can withstand. The materials are best to be selected from materials with high quality and durability.

2.2.1 Coarse Aggregates

The function of coarse aggregate in the mix is to provide stability in the pavement due to interlocking behaviour between the coarse particles. The shapes and surface textures of the aggregates both contribute to the stability of the mix. A good quality aggregate is an aggregate which is hard and round in shape with overall angular surface texture. The quality of the aggregates can be indicated by the means of mechanical test on the aggregates, for example, the Aggregates Compaction Value test which study the compaction strength of aggregates.

According to Section 900 (Flexible Surfacing) of the PLUS Specification

> Coarse aggregates must be hard, unweathered, durable, clean, crushed rock, angular in shape and free from dust. When tested in accordance with BS 812, it should have the following properties: (PLUS Expressway Berhad, 2003)

Aggregate Crushing Value	-	not more than 25
Flakiness Index	-	not more than 30
Water Absorption	-	not more than 2%
Polished Stone Value	-	not less than 49

The type of aggregates used in this research is granite obtained from the laboratory stockpiles. Even though the aggregates have been graded during the production process in quarry, sieve analysis still has to be conducted to get a better gradation of aggregates. Refer to Table 2.1 for the gradation limits for aggregates according to JKR standard for ACWC 20.

Table 2.1: Gradation Limits for Aggregates (ACWC 20)

Sieve Size	Percentage Passing by weight (%)
25mm	100
20mm	92 - 100
14mm	74 - 94
10mm	62 - 82
5mm	44 - 63
2.36mm	32 - 48
1.18mm	21- 35
600μm	13 - 25
300μm	7 - 17
150μm	5 - 13
75 μm	5 - 9

2.2.2 Fine Aggregates

Fine aggregates enhance the stability of the mix with its interlocking characteristics and in the same time fill up the voids left out by the composition of the coarse aggregates. Fine aggregates shall have a good gradation from sieve size of 5mm to 75μm and consists of pure sand, quarry dust or the mixture of both materials. The gradation limits for fine aggregates can be found in Table 2.1.

Textures of fine aggregates are also an important criterion in determining the stability of the mix. It is shown that the stability of mix increases with the increase of the roughness of the fine aggregates. Particles with the bigger size within the fine particles, which have the sieve size of 5mm to 1.18mm, play an important role in providing a rough surface on the pavement where its function is to give a frictional surface for the pavement.

Fine materials from sieve sizes of 600μm to 75μm are also important in a mix to increase the surface area of the aggregates. This will enable the mix to absorb a high content of bitumen and directly enhancing the binding force of the mix. Thus, it can be concluded that the gradation of fine materials is very important and a balance mixture of coarse aggregates and fine aggregates is needed in order to provide required frictional effects and optimum binder content.

2.2.3 Filler

Filler in the mix will act as the final void filler left by the aggregates, namely the coarse and fine aggregates. The most suitable materials that can be used as filler is Portland cement, limestone dust, hydrated chalk or dust from other fine materials which at least 75% of it shall pass 75 micron test sieve. One of the criteria that will affect the suitability of a filler to be used is its fineness. Normally, Ordinary Portland Cement (OPC) will be used as filler in a standard mix. But for this project, we will be using copper slag as a replacement material. The BS sieve size used will be 425μm, 150μm and 75μm. According to the specifications, at least 75% of it shall pass 75μm test sieve.

2.2.4 Binder

Bitumen with penetration from the range of 40 to 200 is commonly used as the binder. The bitumen grade in asphaltic pavement is greatly depending on the climate and the traffic loading. For normal weather and traffic loading, the use of bitumen with penetration 80/100 is the most recommended. Bitumen with lower penetration is needed for extreme weather and traffic loading. For example, the landing track of an airport which has high traffic loading under hot weather needs bitumen with penetration 40/50. On the other hand, bitumen with penetration 180/200 will be used for low temperature climate with low traffic loading. In Malaysia, bitumen 80/100 is the most widely used based on the specifications set by JKR and PLUS. So the binder grade used for the project is the bitumen with penetration 80/100. The bitumen came in drum and directly can be used for specimen preparation.

CHAPTER 3
METHODOLOGY

3.1 INTRODUCTION

Figure 3.1 shows the flow chart which summarizes the steps or procedures for the whole research throughout the course.

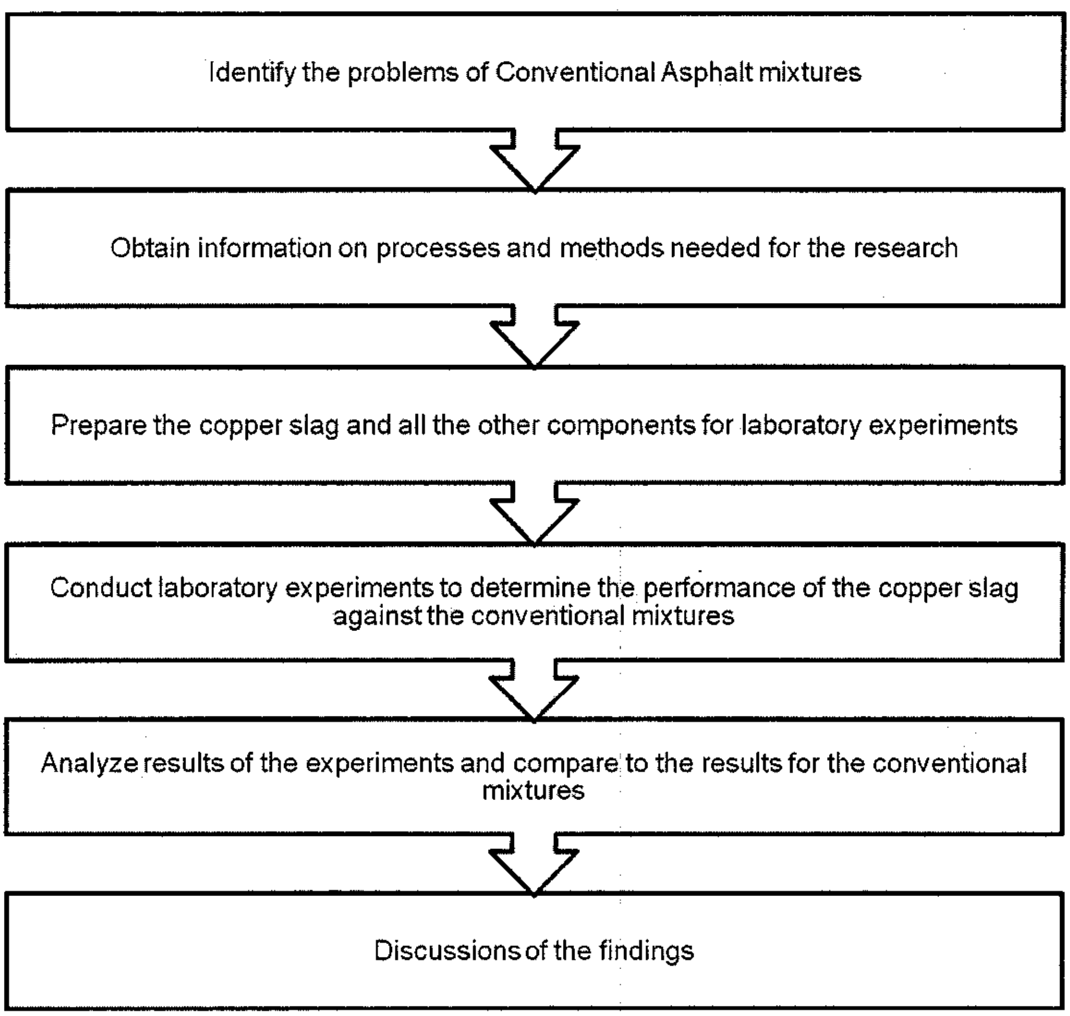

Figure 3.1: Flow Chart of Research

3.2 LABORATORY EXPERIMENTS

This chapter will discuss extensively the method of study including all the tests required. Briefly, the first step in the study is to determine the optimum binder content of conventional mixture where the same binder content will also be used to prepare the modified mixture. Then the comparison of performance for both mixtures will be conducted using Wheel Tracking Test and Beam Fatigue Test. The objectives are to study the feasibility of using copper slag as a substitute of filler in asphaltic pavement and to study the effects and behaviours of the bituminous mix with the existence of copper slag. So the experiments that are conducted:

- XRD/XRF Test
- Sieve Analysis
- Specific Gravity Test
- Marshall Mix Design
- Wheel Tracking Test
- Beam Fatigue Test

3.2.1 XRD/XRF Test

X-ray Diffraction (XRD) is a technique used to determine the existence of different material structures and phases in a sample, based on their characteristic diffraction behaviour under X-ray irradiation of a known wavelength, i.e. each structure or phase will only diffract an incident X-ray at a specific set of incident angles, which can be measured.

X-Ray Fluoresecence (XRF) is a quantitative elemental analysis technique based on the characteristic X-ray emission behaviour of different elements under incident X-ray irradiation. When supplied with high energy radiation (e.g. X-ray), an electron is knocked out of its shell, and replaced with an electron from a higher energy shell. This high-low energy transition results in the emission of photons, the set of wavelengths for which is specific to each element. Examination of relative intensities of different emitted wavelengths can thus give a quantitative measurement of relative quantities of each element in a sample.

3.2.2 Sieve Analysis

The test is conducted to determine the proportions of the mixtures (coarse aggregates, fine aggregates and filler) for preparation of Marshall Mix samples for Marshall Stability Test.

3.2.3 Specific Gravity Test

Specific gravity test will determine the SG for the materials used in bituminous pavement such as fine aggregate, coarse aggregate, OPC, copper slag and also bitumen. The machine used for testing the specific gravity of the mix materials is Ultrapycnometer 1000 Version 2.2.

3.2.4 Marshall Mix Design

Marshall Mix Design is conducted once the design proportions for the mixtures are determined from the Sieve Analysis.

3.2.5 Wheel Tracking Test

The purpose of Wheel Tracking Test is to determine the rutting performance of the asphalt mixtures. The test can also determine the deformation level of the mixtures.

3.2.6 Beam Fatigue Test

The aim of the test is to determine the fatigue life and level of cracking of the asphalt mixtures.

CHAPTER 4
RESULTS & DISCUSSIONS

4.1 XRD/XRF TEST

Table 4.1 shows the percentage of each element after being scanned by the XRF machine. There were no harmful substances which can cause illness were found within copper slag but it may become harmful if exposed to large quantities. Safety measures like wearing protective equipment must be used to prevent anything dangerous from happening.

Table 4.1: Copper Slag's Composition

MgO	Al_2O_3	SiO_2	SO3	K_2O	CaO	TiO_2
1.3 Kcps	4.5 Kcps	35.6 Kcps	3.9 Kcps	18.2 Kcps	38.1 Kcps	9.3 Kcps
0.302%	1.56%	11.9%	0.554%	1.13%	2.65%	0.566%

Cr_2O_3	MnO	Fe_2O_3	CuO	ZnO	As_2O_3	SrO
2.1 Kcps	3.1 Kcps	2300 Kcps	83.7 Kcps	87.1 Kcps	5.1 Kcps	9.1 Kcps
0.0564%	0.104%	73.6%	2.83%	1.91%	0.256%	0.0804%

ZrO_2	MoO_3	Tb_4O_7	Re	Os	PbO	Compton
10.5 Kcps	92.0 Kcps	8.4 Kcps	8.7 Kcps	16.0 Kcps	11.6 Kcps	
0.0753%	0.808%	0.221%	0.624%	0.0148%	0.376%	0.86

Rayleigh	Norm.
1.25	100.00%

4.2 SIEVE ANALYSIS

Table 4.2 shows the final result of the sieve analysis done. This grading was adopted for blending the combined aggregate grading within the specified grading limits of the specification.

Table 4.2: Sieve Analysis Result

Sieve Size	Coarse Aggregate	Fine Aggregate	Filler	Result	JKR Standard
25 mm	100.0	100.0	100.0	100.0	100.0
20 mm	90.4	100.0	100.0	95.2	92- 100
14 mm	71.4	100.0	100.0	85.7	74 - 94
10 mm	52.2	100.0	100.0	76.1	62 - 82
5mm	12.2	100.0	100.0	56.1	44 - 63
2.36 mm	0.0	75.8	100.0	39.1	32 - 48
1.18 mm	0.0	46.7	100.0	26.0	21 - 35
600 μm	0.0	27.6	100.0	17.4	13 - 25
300 μm	0.0	18.0	100.0	13.1	7 - 17
150 μm	0.0	4.7	100.0	7.1	5 - 13
75 μm	0.0	1.8	100.0	5.8	5 - 9

From the results of the sieve analysis, it is found that the mix proportions are conformed to the range specified by JKR. The desired combined grading consists of the following proportions of aggregates as given below:

- Coarse Aggregate **50.0 %**
- Fine Aggregate **45.0 %**
- Filler **5.0 %**

The above-proposed combined aggregates grading and plotted grading curve are shown in Figure 4.1.

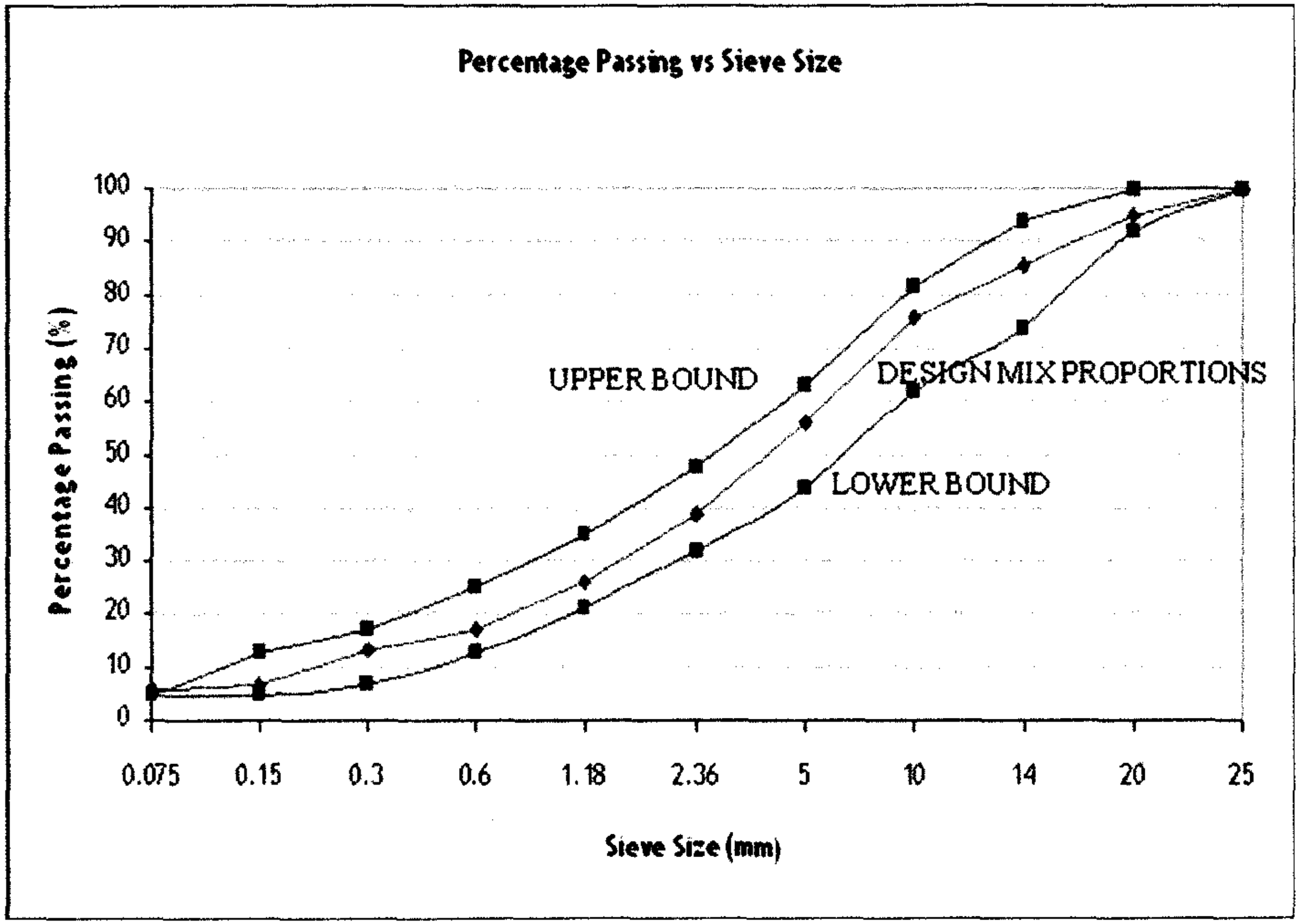

Figure 4.1: Design Mix Proportion Curve

4.3 SPECIFIC GRAVITY TEST

Based on the test, the results are as follow:

- Specific Gravity Coarse Aggregates **2.64**
- Specific Gravity Fine Aggregates **2.74**
- Specific Gravity Cement **3.26**
- Specific Gravity Copper Slag **3.70**
- Specific Gravity Bitumen 80 **1.03**

Combined grading consists of the following proportions of aggregates:

- Coarse Aggregate **50.0 %**
- Fine Aggregate **45.0 %**
- Filler **5.0 %**

The results obtained will be used in calculating the optimum bitumen content for the Marshall Mix Design. The Specific Gravity of Mixed Aggregate for standard mix:

$$\textbf{SGMA} = \frac{P1 + P2 + P3}{\frac{P1}{SG1} + \frac{P2}{SG2} + \frac{P3}{SG3}} = \frac{50 + 45 + 5}{\frac{50}{2.64} + \frac{45}{2.74} + \frac{5}{3.26}} = 2.71$$

While the Specific Gravity of Mixed Aggregate for the modified mix:

$$\textbf{SGMA} = \frac{P1 + P2 + P3}{\frac{P1}{SG1} + \frac{P2}{SG2} + \frac{P3}{SG3}} = \frac{50 + 45 + 5}{\frac{50}{2.64} + \frac{45}{2.74} + \frac{5}{3.70}} = 2.72$$

4.4 MARSHALL MIX DESIGN

After establishing the combine grading, the adopted grading was taken blended and a full scale laboratory design mix was carried out with Marshall Mix Design. Three samples at each bitumen content ranging from 4.5 % to 7.0 % were prepared (Figure 4.2) and compacted to 75 blows at both end of the specimen. The total mix for each sample is 1.2kg. The bitumen content needed for each percentage is shown in Table 4.3. The samples will then be tested with the Marshall Testing Machine (Figure 4.3) to find their stability and flow.

Table 4.3: Bitumen Content for Marshall Mix Design

%	Bitumen Content
4.5	56.5
5.0	63.2
5.5	69.8
6.0	76.6
6.5	83.4
7.0	90.3

Figure 4.2: Marshall Mix Design Samples

Figure 4.3: Sample tested with Marshall Testing Machine

4.4.1 Ordinary Portland Cement (OPC) as Filler

Appendix B shows the results from the Marshall Mix Design Test when Ordinary Portland Cement (OBC) is used as filler in the mix. Meanwhile Figure 4.4 until Figure 4.8 show the graphs plotted from the result obtained from the parameters in Appendix B, The following graphs are plotted vs. the binder content:

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

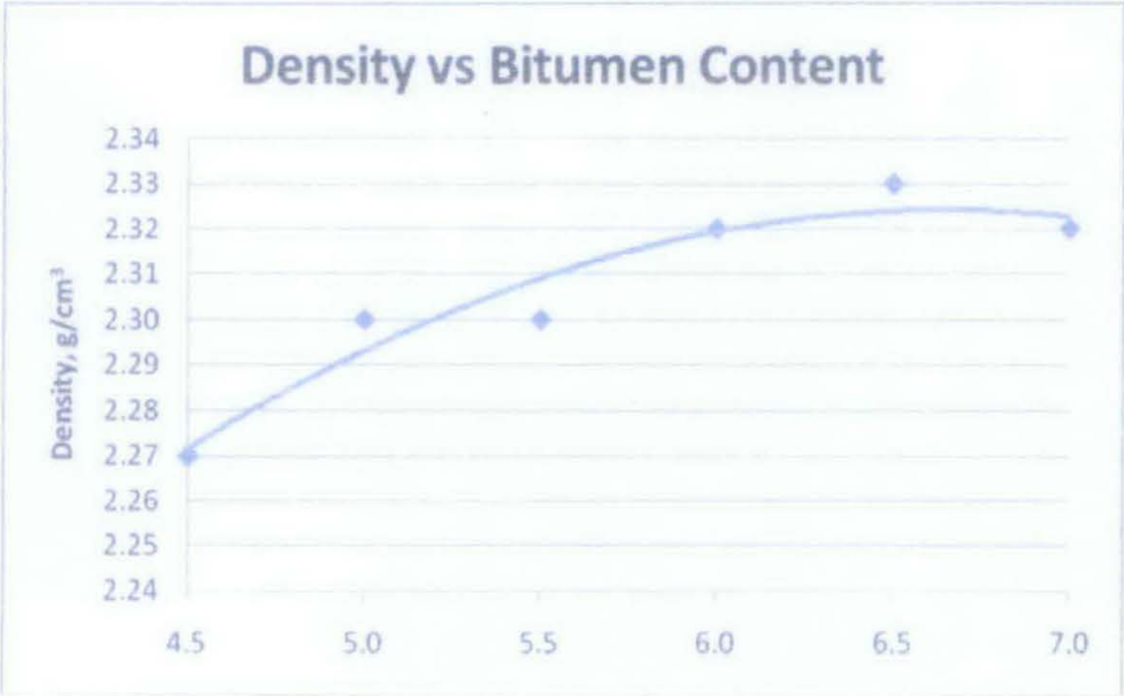

Figure 4.4: Density vs. Bitumen Content

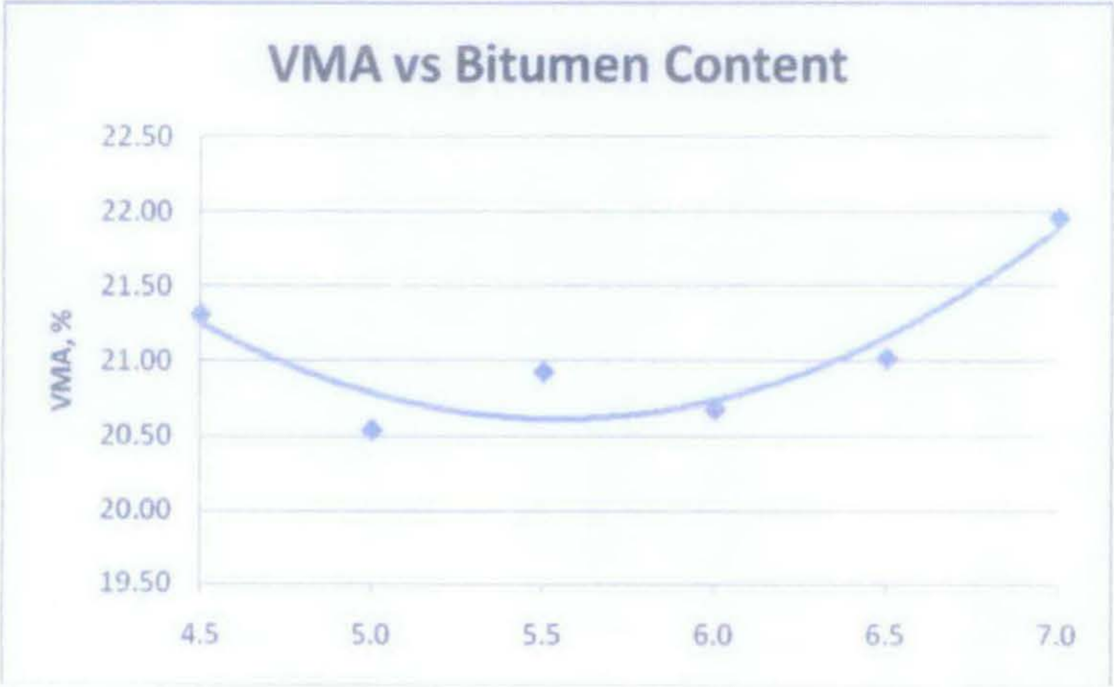

Figure 4.5: VMA vs. Bitumen Content

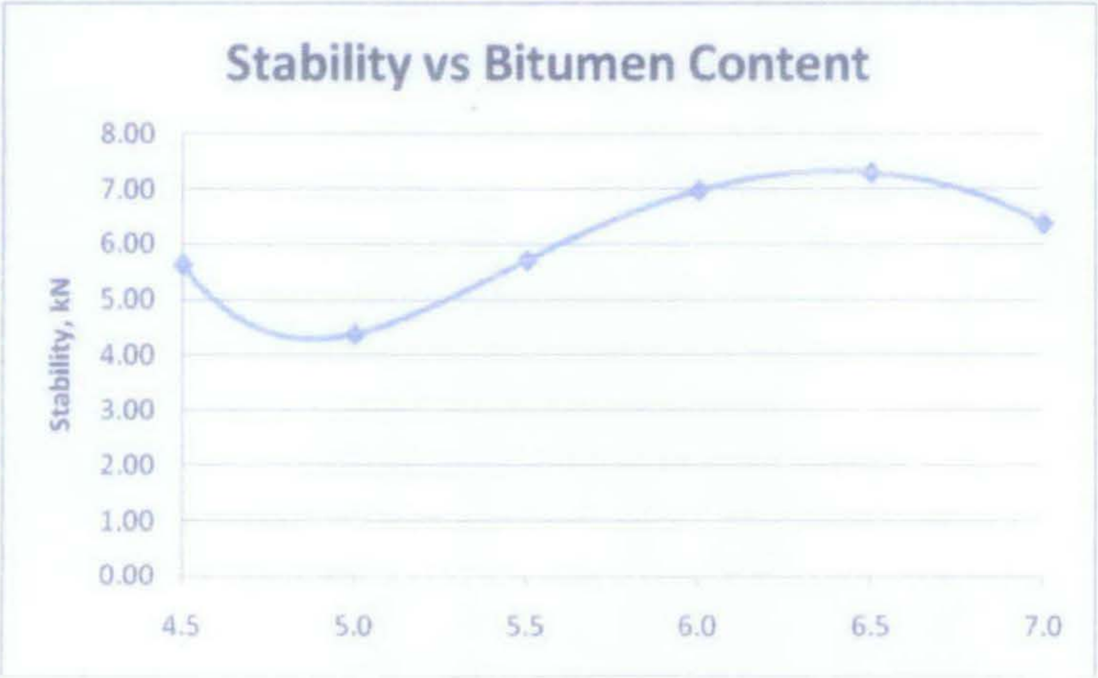

Figure 4.6: Stability vs. Bitumen Content

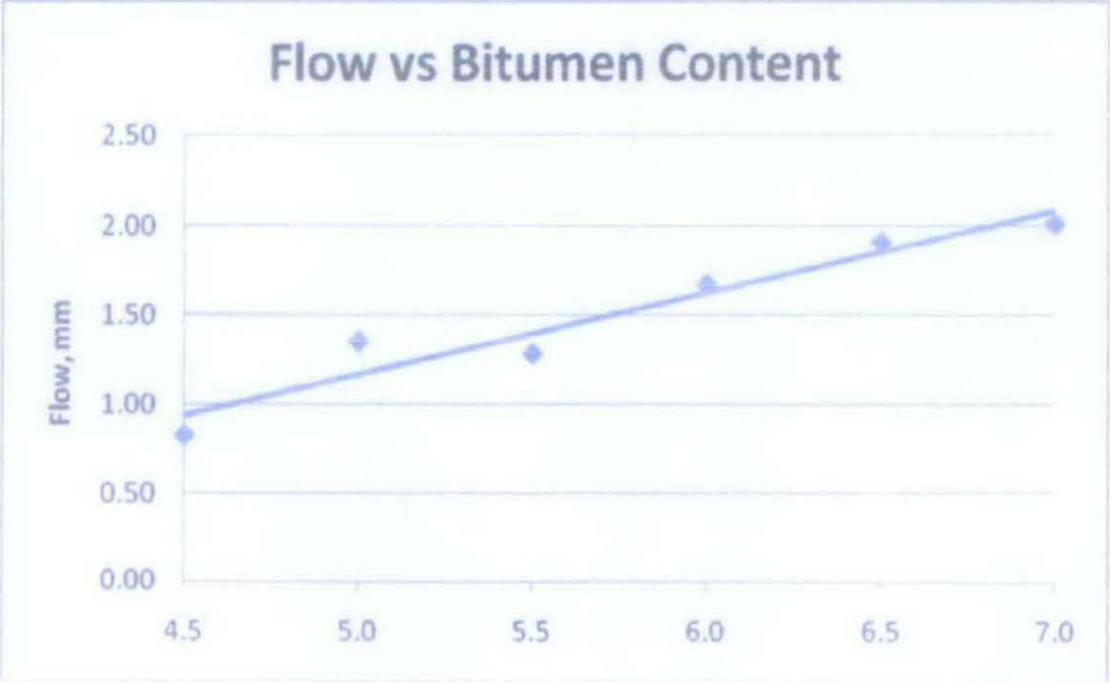

Figure 4.7: Flow vs. Bitumen Content

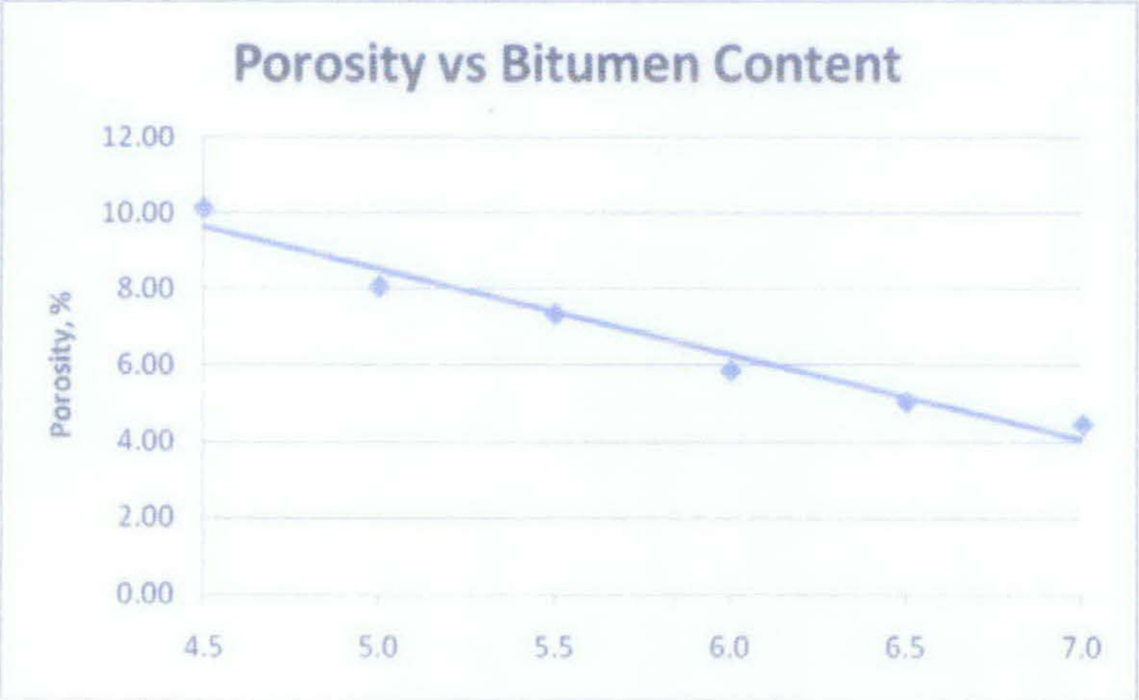

Figure 4.8: Porosity vs Bitumen Content

From these graphs, we can determine the Optimum Bitumen Content (OBC) needed for mixing by getting the average value of optimum binder content from stability, density and VMA graphs. Table 4.4 shows the value for each parameter stated above.

Table 4.4: Optimum Bitumen Content (OBC) for OPC

Parameter	OBC (% by weight)
Density	6.6
Stability	6.375
VMA	5.6

Optimum Bitumen Content (OBC) $= \dfrac{6.6+6.375+5.6}{3} = 6.19\%$

4.4.2 Copper Slag as Filler

Appendix B shows the results from the Marshall Mix Design Test when Copper Slag is used as filler in the mix. Meanwhile Figure 4.9 until Figure 4.13 show the graphs plotted from the result obtained from the parameters in Appendix B.

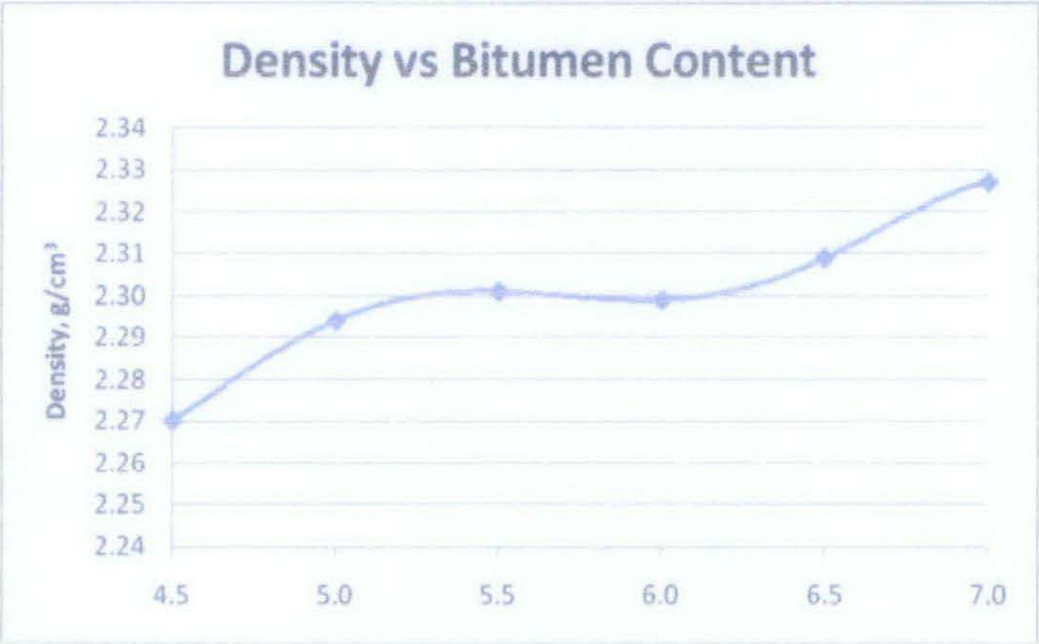

Figure 4.9: Density vs Bitumen Content

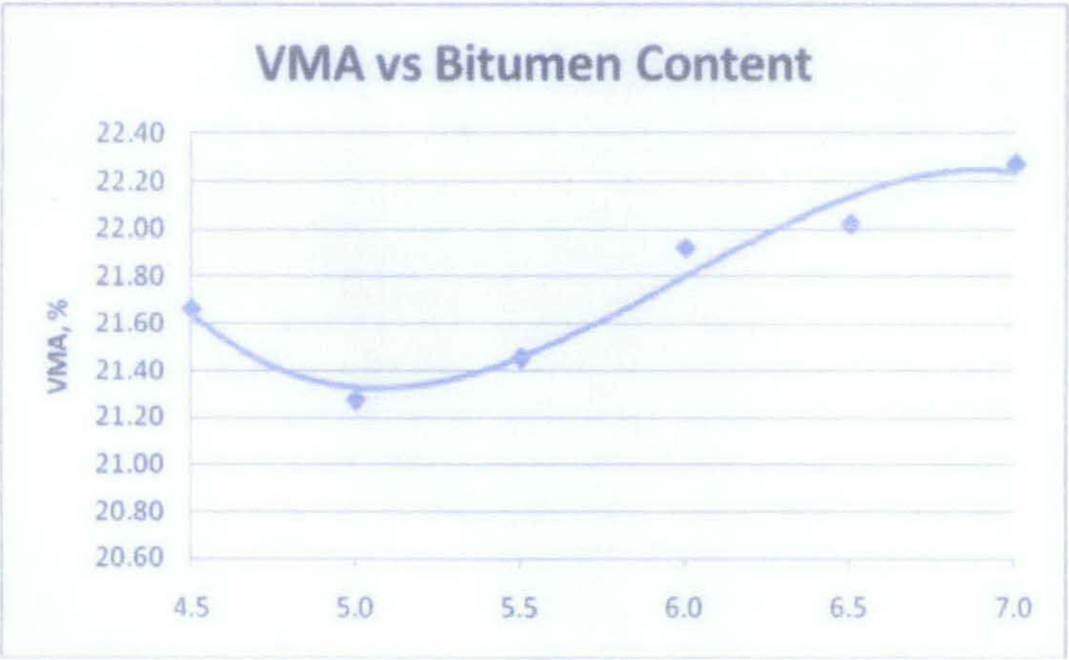

Figure 4.10: VMA vs Bitumen Content

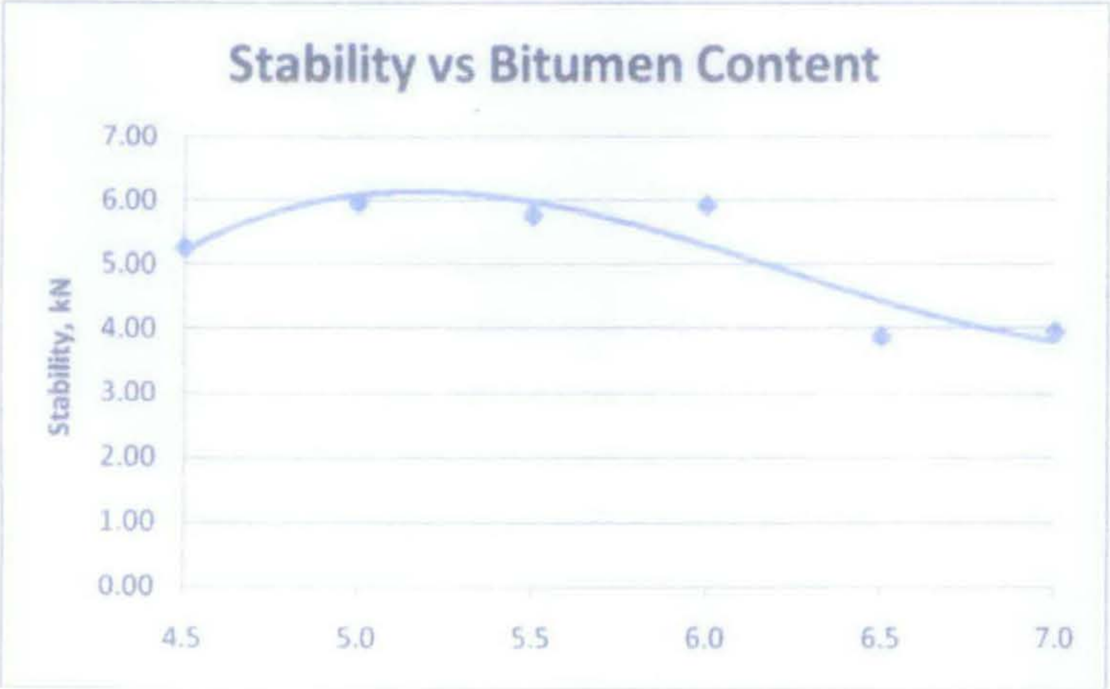

Figure 4.11: Stability vs Bitumen Content

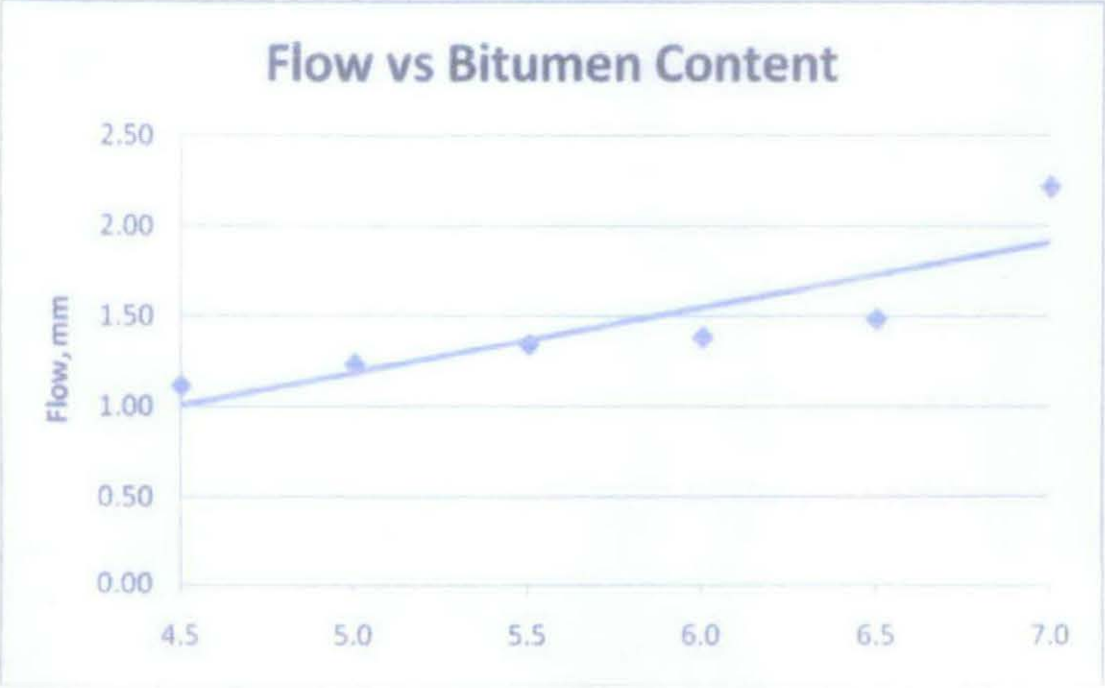

Figure 4.12: Flow vs Bitumen Content

4.5 WHEEL TRACKING TEST

The test was conducted by preparing an asphaltic mixture slab (Figure 4.14) to be run on the wheel tracker machine (Figure 4.15) for 45 minutes. The results obtained are shown in Appendix C and are then plotted in a graph so that a direct comparison can be made between the slabs made out of the standard mix and the modified mix. The specimens were prepared based on calculations shown in Table 4.6. The total mix for each sample is 10kg

Figure 4.4: Wheel Tracking Sample

Figure 4.15: Wheel Tracking Machine

Table 4.6: Calculation for Wheel Tracking slabs

	%	Mass (g)	OPC	Copper Slag
Coarse Aggregate	50	5000		
Fine Aggregate	45	4500		
Filler	5	500		
OBC (%)			6.19	5.22
Binder Content (g)			**659.84**	**550.75**

Based on the results in Appendix C, a graph of depth versus time was plotted (Figure 4.16). Based on the graph in Figure 4.16, the deflection rates for both standard and modified mix were found from the slope:

- Deflection rate for standard mix **0.167 mm/min**
- Initial deflection rate for modified mix **0.244 mm/min**
- End deflection rate for modified mix **0.056 mm/min**

It was found that the rut depth for modified mix slabs is slightly lesser although it has a higher initial deformation, but after 30 minutes, the deformation is already constant compared to the standard mix which continues to rise. This means that the slab with modified mix will perform better in later stages of life.

Figure 4.16: Rut Depth vs Time for Wheel Tracking Test

4.6 BEAM FATIGUE TEST

The beam fatigue test is conducted to compare the performance between the conventiol mix and the modified mix. Table 4.7 shows the amount of materials needed for the Bez Fatigue Test. The total mix for each sample (Figure 4.17) is 7.478kg. These samples w then be tested with the Beam Fatigue Apparatus (Figure 4.18).

Table 4.7: Calculation for Beam Fatigue Test

	%	Mass (g)	OPC	Copper Slag
Coarse Aggregate	50	**3739**		
Fine Aggregate	45	**3365.1**		
Filler	5	**373.9**		
OBC (%)			6.19	5.22
Binder Content (g)			**493.43**	**411.85**

Figure 4.17: Beam Fatigue Test Sample

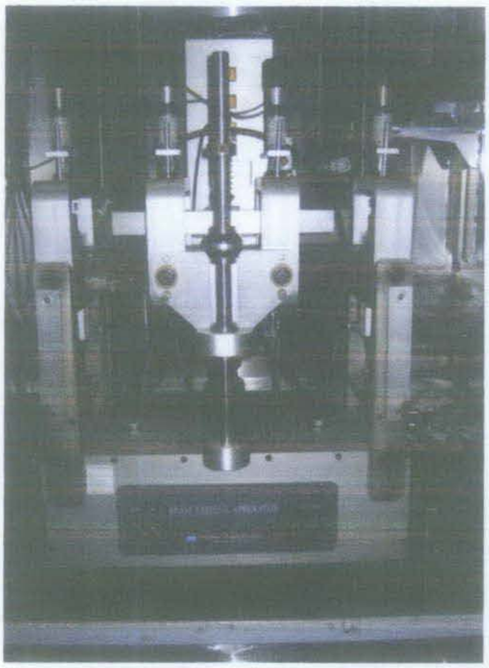

Figure 4.18: Beam Fatigue Apparatus

Figure 4.19 shows the graph of stiffness versus the number of cycles for the beam fatigue test while Table 4.8 shows the result obtained for the experiment.

Table 4.8: Beam Fatigue Test Result

	Conventional Mix	Modified Mix
Initial Flexural Stiffness (Mpa)	5199	7767
Termination Stiffness (Mpa)	2600	3883
Failure (Cycles)	32760	232440

For conventional mix, the initial flexural stiffness is 5199 MPa. The graph shows the stiffness of the specimen decrease exponentially with cycle until it fails. The result also shows the termination stiffness of the mix which is at 2600 MPa. Termination stiffness is the value of stiffness the specimen can withstand before failing. The specimen failed at 32760 cycles.

Meanwhile for modified mix, the initial flexural stiffness is 7767 MPa while the termination stiffness is 3883 MPa. The sample fails at 232440 cycles. Both the initial and termination stiffness for the modified mix are higher than that of conventional mix. This shows that the modified mix is much stiffer than the conventional mix which will increase the fatigue life of the specimen and is more durable against cracking.

Figure 4.19: Stiffness vs Cycle for Beam Fatigue Test

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

From the researches and works done, it was found that:

- The modified mix needs less bitumen content than the conventional mix for mixing bituminous pavement
- The modified mix performs better than conventional mix in rutting in the later stages of life although the initial result shows signs of weakness
- The modified mix also performs better than conventional mix in stiffness which will help to increase the fatigue life and the durability of bituminous pavement

Getting a more durable and higher performance asphaltic pavement means lesser money needed to maintain the road after the construction process. Local authorities like Jabatan Kerja Raya (JKR) maybe can start incorporating the method into their system because countries such as United States, United Kingdom and even India have already moved a step forward in using copper slag in their pavements.

5.2 RECOMMENDATION

It is recommended that this project should be continued for students for semesters to come. But the percentage of the materials used such as the coarse and fine aggregates, fillers and binders can be authored to find the most suitable mix. The authored mix can then be compared with the results obtained from previous semester's project and compared to see which the best is. If the mix is within the specified standard set by JKR and PLUS, then most probably copper slag can start to be incorporated into the asphalt pavement and be used widely across the country because using copper slag not also reduce the problem of our waste management but also save cost in terms of production and maintenance while improving the quality of our pavement.

There are a few suggestions need to be pointed out if this project is continued in the future. It involves different processes such as:

- Determine the shape and size of filler particles and whether they have any effects on the overall result and performance of the samples mixed and tested
- Determine the effects Fe_2O_3 and SiO_2 have on asphaltic pavement since they are the 2 most components in copper slag
- During Marshall Mix Design sample preparation, make sure the height of the sample is 63 ± 1.5mm as per standard
- Calculation for Optimum Bitumen Content (OBC) should include porosity and flow so the result would be more reliable
- Investigate why the result for wheel tracking test for the modified mix goes on a plateau after a while
- It would be better if the mix that is using copper slag as filler could be laid on site for a duration of 6 to 12 months or maybe more so that the performance of the laid pavement could be analyzed for further studies and improvements

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XRD/XRF: X-Ray Technique Laboratory
www.mtec.or.th/th/labs/xrd&xrf

APPENDICES

APPENDIX A

- Schedule for First Semester of Two Semester of Final Year Project
- Schedule for Second Semester of Two Semester of Final Year Project

APPENDIX B

- Marshall Mix Design Test Result (Standard Mix)
- Marshall Mix Design Test Result (Modified Mix)

APPENDIX C

- Wheel Tracking Test Result

APPENDIX A

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Searching Topics														
2	Appointing Supervisor														
3	Submission of FYP Topic														
4	Define the Project														
5	Research on the Project														
6	Preparation and Submission of Preliminary Report														
7	Preparation of Specimens														
8	Laboratory Experiments														
9	Preparation and Submission of Progress Report														
10	Preparation and Submission of Interim Report														
11	Preparation of FYP Presentation														
12	FYP Presentation														

Schedule for First Semester of Two Semester of Final Year Project

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Preparing Specimens	■													
2	Laboratory Experiments	■	■	■	■	■	■	■	■	■					
3	Preparing of Progress Report 1		■	■											
4	Submission of Progress Report 1				■										
5	Laboratory Result Analysis		■	■	■	■	■	■	■						
6	Preparing of Progress Report 2					■	■								
7	Submission of Progress Report 2							■							
8	Preparing First Draft Dissertation Final Report								■	■					
9	Submission of First Draft Dissertation Final Report										■				
10	Preparation of FYP Presentation											■	■		
11.	FYP Presentation													■	
12	Submission of Project Dissertation														■

Schedule for Second Semester of Two Semester of Final Year Project

APPENDIX B

Marshall Mix Design Test Result (Standard Mix)

Sample Designation	Height (mm)	Volume (cm3)		Weight (gm)		Marshall Stability (kN)				Flow (mm)	
		Volume	Average	Air	Water	Measured	CF	Corrected	Average Stability	Flow (mm)	Average Flow
4.5.1	69.38	564.0		1243.5	679.5	6.93	0.89	6.168		0.41	
4.5.2	69.07	536.2	544.4	1227.7	691.5	5.31	0.89	4.726	5.631	1.56	0.817
4.5.3	69.05	533.0		1232.5	699.5	6.74	0.89	5.999		0.48	
5.0.1	69.06	539.5		1239.0	699.5	3.97	0.89	3.533		1.34	
5.0.2	67.64	534.0	538.3	1235.5	701.5	5.60	0.93	5.208	4.382	2.07	1.347
5.0.3	69.75	541.5		1245.5	704.0	4.95	0.89	4.406		0.63	
5.5.1	68.38	536.0		1237.5	701.5	6.16	0.89	5.482		2.11	
5.5.2	68.50	536.5	536.8	1239.0	702.5	7.31	0.89	6.506	5.698	0.69	1.280
5.5.3	67.38	538.0		1234.5	696.5	5.49	0.93	5.106		1.04	
6.0.1	67.60	534.5		1244.0	709.5	6.15	0.93	5.720		1.41	
6.0.2	67.65	541.5	540.0	1258.5	717.0	8.11	0.93	7.542	6.957	1.50	1.670
6.0.3	68.32	544.0		1262.5	718.5	8.55	0.89	7.610		2.10	
6.5.1	67.32	534.5		1244.0	711.0	8.79	0.93	8.175		1.50	
6.5.2	67.52	543.5	540.3	1258.5	715.5	6.13	0.93	5.701	7.282	2.01	1.913
6.5.3	67.65	543.0		1262.5	724.0	8.57	0.93	7.970		2.23	
7.0.1	68.32	546.5		1267.5	721.0	7.75	0.89	6.898		2.24	
7.0.2	66.71	537.0	543.2	1253.0	716.0	6.20	0.93	5.766	6.357	2.24	2.010
7.0.3	67.01	546.0		1267.0	721.0	6.89	0.93	6.408		1.55	

Specific Gravity					Porosity (%)		Density (gm/cm3)		VMA
Bulk	Average Bulk	Aggregate	max	Effective Aggregate	Calculated	Average	Calculated	Average Density	
2.205		2.710	2.525	2.710	12.679		2.205		
2.290	2.269	2.710	2.525	2.710	9.319	10.139	2.290	2.269	21.307
2.312		2.710	2.525	2.710	8.418		2.312		
2.297		2.710	2.525	2.710	8.353		2.297		
2.314	2.304	2.710	2.525	2.710	7.671	8.079	2.314	2.304	20.535
2.300		2.710	2.525	2.710	8.212		2.300		
2.309		2.710	2.525	2.710	7.171		2.309		
2.309	2.304	2.710	2.525	2.710	7.145	7.352	2.309	2.304	20.932
2.295		2.710	2.525	2.710	7.741		2.295		
2.327		2.710	2.525	2.710	5.721		2.327		
2.324	2.324	2.710	2.525	2.710	5.855	5.855	2.324	2.324	20.680
2.321		2.710	2.525	2.710	5.990		2.321		
2.330		2.710	2.525	2.710	4.906		2.330		
2.316	2.326	2.710	2.525	2.710	5.468	5.051	2.316	2.326	21.022
2.333		2.710	2.525	2.710	4.779		2.333		
2.319		2.710	2.525	2.710	4.654		2.319		
2.333	2.324	2.710	2.525	2.710	4.077	4.445	2.333	2.324	21.957
2.321		2.710	2.525	2.710	4.604		2.321		

Marshall Mix Design Test Result (Modified Mix)

Sample Designation	Height (mm)	Volume (cm3)		Weight (gm)		Marshall Stability (kN)				Flow (mm)	
		Volume	Average	Air	Water	Measured	CF	Corrected	Average Stability	Flow (mm)	Average Flow
4.5.1	67.85	535.0		1208.5	673.5	5.63	0.93	5.236		0.81	
4.5.2	70.19	540.5	541.0	1237.5	697.0	6.52	0.86	5.607	5.264	1.95	1.113
4.5.3	69.67	547.5		1238.0	690.5	5.56	0.89	4.948		0.58	
5.0.1	69.39	546.0		1247.5	701.5	7.82	0.89	6.960		1.28	
5.0.2	68.83	533.0	537.7	1223.5	690.5	6.35	0.89	5.652	5.959	1.67	1.230
5.0.3	66.88	534.0		1228.5	694.5	5.66	0.93	5.264		0.74	
5.5.1	67.53	532.5		1229.5	697.0	6.28	0.93	5.840		1.06	
5.5.2	68.09	545.5	537.3	1249.0	703.5	7.27	0.93	6.761	5.775	1.46	1.327
5.5.3	67.43	534.0		1230.0	696.0	5.08	0.93	4.724		1.46	
6.0.1	68.96	552.0		1275.5	723.5	7.98	0.89	7.102		1.39	
6.0.2	68.29	538.5	543.0	1236.0	697.5	4.98	0.93	4.631	5.929	1.08	1.380
6.0.3	67.73	538.5		1234.0	695.5	6.51	0.93	6.054		1.67	
6.5.1	67.78	543.0		1259.0	716.0	4.52	0.93	4.204		2.19	
6.5.2	70.15	560.5	545.8	1284.0	723.5	3.30	0.86	2.838	3.876	1.10	1.483
6.5.3	67.74	534.0		1237.0	703.0	4.93	0.93	4.585		1.16	
7.0.1	69.49	550.0		1269.0	719.0	3.87	0.89	3.444		2.32	
7.0.2	68.32	536.0	542.7	1258.5	722.5	4.23	0.89	3.765	3.952	2.19	2.223
7.0.3	68.37	542.0		1260.0	718.0	5.22	0.89	4.646		2.16	

Specific Gravity					Porosity (%)		Density (gm/cm3)		VMA
Bulk	Average Bulk	Aggregate	max	Effective Aggregate	Calculated	Average	Calculated	Average Density	
2.259		2.724	2.536	2.724	10.930		2.259		
2.290	2.270	2.724	2.536	2.724	9.721	10.497	2.290	2.270	21.664
2.261		2.724	2.536	2.724	10.839		2.261		
2.285		2.724	2.536	2.724	9.219		2.285		
2.295	2.294	2.724	2.536	2.724	8.794	8.868	2.295	2.294	21.265
2.301		2.724	2.536	2.724	8.592		2.301		
2.309		2.724	2.536	2.724	7.563		2.309		
2.290	2.301	2.724	2.536	2.724	8.335	7.894	2.290	2.301	21.447
2.303		2.724	2.536	2.724	7.785		2.303		
2.311		2.724	2.536	2.724	6.795		2.311		
2.295	2.299	2.724	2.536	2.724	7.417	7.260	2.295	2.299	21.919
2.292		2.724	2.536	2.724	7.567		2.292		
2.319		2.724	2.536	2.724	5.776		2.319		
2.291	2.309	2.724	2.536	2.724	6.905	6.181	2.291	2.309	22.021
2.316		2.724	2.536	2.724	5.862		2.316		
2.307		2.724	2.536	2.724	5.540		2.307		
2.348	2.327	2.724	2.536	2.724	3.874	4.746	2.348	2.327	22.267
2.325		2.724	2.536	2.724	4.825		2.325		

APPENDIX C

Wheel Tracking Test Result

Time (Minutes)	Depth (mm)	
	Standard Mix	Modified Mix
1	0.0	1.4
2	0.0	2.1
3	0.1	2.5
4	0.2	2.8
5	0.3	3.1
6	0.5	3.4
7	0.6	3.7
8	0.8	4.0
9	1.0	4.2
10	1.2	4.5
11	1.4	4.7
12	1.7	4.9
13	2.0	5.1
14	2.3	5.2
15	2.5	5.4
16	2.7	5.6
17	2.9	5.8
18	3.2	5.9
19	3.4	6.0
20	3.5	6.1
21	3.7	6.3
22	3.9	6.4
23	4.1	6.5
24	4.2	6.5
25	.4.4	6.5
26	4.5	6.5
27	4.7	6.5
28	4.9	6.5
29	5.0	6.5
30	5.2	6.5
31	5.4	6.6
32	5.5	6.6
33	5.7	6.6
34	5.8	6.6
35	6.0	6.6
36	6.1	6.6
37	6.2	6.6
38	6.4	6.6
39	6.6	6.6
40	6.7	6.6
41	6.9	6.6
42	7.0	6.6
43	7.1	6.6
44	7.3	6.6
45	7.4	6.6