Usage of Iron Sludge As Filler in ACWC 20 Mix

by

Mohd Juzaili Bin Mohd Kabri

Dissertation submitted in partial fulfilment of
the requirements for the
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Universiti Teknologi PETRONAS
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CERTIFICATION OF APPROVAL

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Civil Engineering Programme
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TRONOH, PERAK

January 2008

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 JUZAILI BIN MOHD KABRI

ABSTRACT

Chemical processes produce waste, and waste has to be disposed of, which costs money. Creating more efficient processes is one way that waste can be minimized and money saved. But another strategy is to use the waste material as part of industry activities. This research project studies the effects of the iron sludge from Groundwater Treatment Plant as filler in asphaltic pavements substituting the cement. Considering the high percentage of iron sludge produced in every Groundwater Treatment Plant, hence it is very important that the iron sludge can be recycled and used in pavement construction. The objective of this research is to produce at least the same performance of the conventional asphaltic pavement by using iron sludge as filler replacing the cement. The high cost in cement industry nowadays also becomes one of the factors that this research is conducted since by replacing the iron sludge as filler would decrease the cost of asphaltic pavement. The scope of this research is mainly to compare the performance of the modified mix with the conventional ACWC 20 mix. Based from the laboratory testing results, it shows that the modified mix that using iron sludge as filler have achieved better performance compare to the conventional ACWC 20 mix.

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

Iron sludge is generally the by-product from any groundwater treatment facilities. It is disposed at landfills in the form of de-watered sludge or incinerator ash. Nowadays, with the development in science and technology, people can now foresee the huge potential in utilizing sludge as an alternative resource especially for the use in construction and pavement industry.

Therefore, utilizing the iron sludge from the Groundwater Treatment Plant into replacing cement or limestone as filler in asphaltic pavement would be a good start in making benefits of the waste material that would be disposed anyway.

There are many types of flexible pavement that are often used in Malaysia such as Asphaltic Concrete Basecourse, Asphaltic Concrete Wearing Course and Dense Bitument Macadam. The other type of pavement is rigid pavement which is constructed by Portland cement concrete. There are pros and contras between these two pavements, but the purpose of the study is to evaluate the behavior and performance of the asphaltic pavement using iron sludge as filler as compared with the conventional asphalt pavement. To be specific, this study 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 iron sludge as filler based on results gain in several laboratory testing.

1.2 Problem Statement

The main component that would be discharge at any Groundwater Treatment Plant is iron sludge, therefore it is very wise that the iron sludge will be taken care wisely other than disposing it.

Even though the percentage of filler in the asphaltic pavement are not high, but still it affects the cost since cement is well-known to be one of the expensive materials in constructions.

1.3 Objectives

The objective of the project is to study;

i. The possibility of using iron sludge as filler in pavement material.

1.4 Scope of Study

The scope of the study is to compare the performance of the asphalt pavement that uses iron sludge as filler and the conventional Asphaltic Concrete Wearing Course (ACWC) 20. The comparison will be made by doing the tests on the Sieve Analysis, Marshall Properties, Wheel Tracking Test, Dynamic Creeping Test and Beam Fatigue Test. The result will show the pavement's performance on the fatigue and rutting. Specific Gravity and Scanning electron microscope (SEM) value for both cement and iron sludge also will be determined.

CHAPTER 2
LITERATURE REVIEW/THEORY

Asphaltic Concrete Wearing Course (ACWC) 20 is a continuously graded mixture with small maximum particle sizes. Its mixture of mineral aggregate, filler and bituminous binder forms an interlocking structure that contributes to the strength and performance of the design mix. ACWC is commonly used throughout the world including Malaysia. Based on current practice, the accepted ACWC mix in Malaysia highway is ACWC 20. The conventional mix use cement as filler for the asphaltic pavements.

Many researches have studied the effects of mineral fillers on the behavior of asphalt mixes (Ibrahim Asi and Abdullah Assa'ad., 2005). Mineral fillers include dust from the crushing and screening of aggregates, lime, Portland cement, and fly ash. Although fillers usually contribute small portion, 5–7%, of the total aggregate mix, they have great effect on the mix properties.

Typically, fillers are used to improve bond between asphalt cement and aggregate, lower the optimum asphalt content, increase the density, and increase the stability (Ibrahim Asi and Abdullah Assa'ad., 2005). The main reason for using these fillers and some other types of modifiers is to improve the performance of paving mixture to meet requirements under prevailing conditions. Another early method of asphalt modification consisted of mixing two or more asphalt binders of different paving grades or sources. This technique has continued through the years and often delivers a satisfactory end product. One major problem with this technique is that sometimes asphalt is not chemically compatible. Compatibility cannot be predicted effectively and leads to premature pavement distresses (Ibrahim Asi and Abdullah Assa'ad., 2005). Ibrahim Asi and Abdullah Assa'ad., (2005) has listed the following factors, which have led to increasing interest in asphalt modification:

i. The growing amount of traffic related distresses resulting from escalating traffic demands on all types of asphalt pavements. Higher volumes of traffic, heavier loads, and increasing tire pressures are characteristics of these traffic-related distresses.
ii. The increase in the cost of asphalt binders and the trend in refineries of producing lighter fuels on the account of asphalt production.
iii. Growing economic pressures that lead to thinner pavements and differed maintenance.
iv. Excess supplies of industrial by-products and waste materials. This promotes the idea of converting them into asphalt modifiers.
v. Continued low-temperature thermal cracking and high temperature deformation distresses.

Although the original idea of using asphalt modifiers was to get rid of waste materials, the trend is to produce high-tech modifiers to obtain specific improvements in asphalt binders (Ibrahim Asi and Abdullah Assa'ad., 2005). Modifiers have been used in asphalt binders to design against or to repair pavements from the following distresses: surface defects (raveling and stripping), structural defects (rutting, shoving, and distortion), and cracking (fatigue and thermal). Ibrahim Asi and Abdullah Assa'ad. (2005) suggested that modified asphalt– aggregate mixture should achieve the following requirements:

i. Higher stiffness at high temperature to resist rutting and shoving.
ii. Lower stiffness at low temperature conditions to reduce thermal cracking.
iii. Lower stiffness at very high temperatures (mixing and compaction temperatures)
iv. Expedite pumping of the asphalt binder and mixing and compaction of the asphalt mixture.
v. Increase adhesion between the binder and the aggregate to resist stripping.

Numerous waste materials result from manufacturing operations, service industries, sewage treatment plants, households and mining. Legislation has been enacted by several states in recent years to either mandate the use of some waste materials or to examine the feasibility of such usage. Prithvi S. Kandhal. (1992) categorized the wastes materials as follows:

i. Industrial wastes such as cellulose wastes, wood lignins, bottom ash and fly ash;
ii. Municipal/domestic wastes such as incinerator residue, scrap rubber, iron sludge, waste glass and roofing shingles
iii. Mining wastes such as coal mine refuse.

Numerous waste materials result from every aspect of society including manufacturing, service industries, sewage treatment plants, households and mining. The disposal of waste products is primarily done as follows:

i. Landfills
ii. Incineration, and
iii. Recycling in other products

However, problems are being experienced because of the insufficient capacity of landfills, air pollution associated with incinerators, and limited alternatives for recycling. Legislation has been enacted by several states in recent years to either mandate the use of some waste materials or to examine the feasibility of such usage.

Corporate Author:
Dartmouth Toxic Metals Research Program (2003)

Iron overdoses can be severe in human beings, especially children, but its effects within ecosystems can be far more widespread and circuitous. The undissolved particles can harm the aquatic ecosystem by blocking light and blanketing stream beds, which obscures food sources for bottom dwellers. Iron can damage aquatic communities in more subtle ways. Aquatic organisms such as algae and bacteria can thrive in iron-rich environments, such as effluent from iron ore mining plants.

When this mineral-rich effluent is pumped into an established and stable aquatic ecosystem, growth of algae and iron-metabolizing bacteria is stimulated.

Corporate Author:

ASCE Research Library (2001)

There are four major compounds in iron sludge which are aluminium oxide (Al_2O_3,) silicon oxide (SiO_2), calcium oxide (CaO) and iron oxide (Fe_2O_3). The properties of those compounds are shown in Table 1.1.

Table 1.1: Components in Iron Sludge

Constituent Compound	Properties
Al_2O_3 Aluminium oxide	- Other name: Alumina, Aluminium(III) Oxide - Molar mass: 101.96 g/mol - Density and phase: 3.97 g/cm³, solid - Solubility in water in water: Insoluble. - Melting point: 2054°C - Boiling point: ~3000°C - Crystal structure: Cubic
SiO_2 Silicon dioxide	- Other name: Silica - Molar mass: 60.1 g/mol - Appearance: White or colourless solid (when pure) - Density and phase: 2.6 g/cm^3, solid - Solubility in water: Insoluble in water - Melting point: 1710 °C - Boiling point: 2230 °C - Crystal structure: Various
CaO Calcium oxide	- Other name: Lime, quicklime or burnt lime - Molar mass: 56.1 g/mol - Appearance: White solid - Density and phase: 3350 kg/m^3, solid - Solubility in water: Reacts in water - Melting point: 2572 - Boiling point: 2850 - Structure: Face-centered cubic
Fe_2O_3 Iron(III) oxide	- Other name: Ferric oxide, hematite, red iron oxide, synthetic maghemite, colcothar, or simply rust - Molar mass: 159.69 g/mol red-brown solid - Appearance: Red-brown solid - Density and phase: 5.24 g/cm^3, solid - Solubility in water: Insoluble - Melting point: 1565 °C

CHAPTER 3
METHODOLOGY/PROJECT WORK

Figure 3.1 shows the project flowchart for this project:

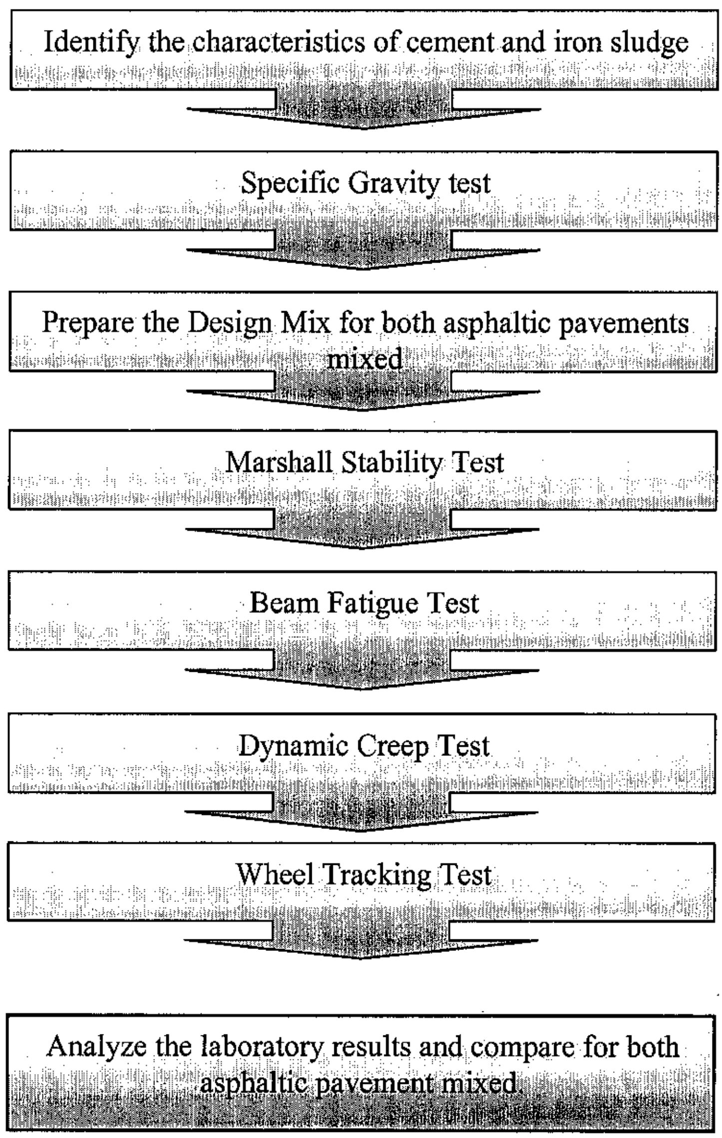

Figure 3.1: Project Flowchart

3.1 Drying Process

Drying process was done for several times so that the materials are 100% free from moisture. The iron sludge was dried in the oven separately in different trays for each material with temperature 105^0C for 24 hours or one night.

3.2 Sieving Process

All of the materials were sieved accordingly to the specifications as mentioned above.

3.3 Tools Required

The tools that were needed in completing this project were basically the apparatus for all related laboratory tests and the materials for the design mix.

3.3.1 SEM

Scanning electron microscope (SEM) is a type of electron microscope capable of producing high resolution images of a sample surface as shown in Figure 3. Due to the manner in which the image is created, SEM images have a characteristic three dimensional appearance and are useful for judging the surface structure of the sample.

3.3.2 Specific Gravity Test

The machine that was needed to test the specific gravity of the mix materials is Ultrapycnometer 1000 Version 2.2.

3.3.3 Marshall Stability Test

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 some 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.

3.3.4 Beam Fatigue Test

This is a test that applies repeated flexural bending to an asphalt (or, other material) specimen and measures the applied force and the resulting beam deflection using an on-specimen Linear Variable Displacement Transformer (LVDT). The test may be controlled in either strain or stress modes and the loading pulse wave shape is sinusoidal with a frequency of between 0.02 and 100 Hz. In strain control mode, the deflection of the specimen is measured and the load adjusted so that the specimen experiences a constant level of strain on each load cycle. In stress control mode, the applied force is kept constant and the beam deflection is monitored. If any creep occurs, then the minimum and maximum load levels are adjusted to maintain a straight beam. Various parameters are calculated from the acquired data as the test proceeds and these are displayed in tabular and plot form. The tabulated test data is updated every 10th cycle, while the plot data is collected linearly up to 10000 cycles, then periodically on a logarithmic basis. The main required equipment to be used is UTM Machine.

3.3.5 Dynamic Creep Test

The Dynamic Creep Test is a test that applies a repeated pulsed uniaxial stress/load to an asphalt (or, other material) specimen and measures the resulting deformations in the same axis and/or radial axis using Linear Variable Displacement Transformers (LVDTs). The test can also be conducted under confined conditions using a standard triaxial pressure cell or the IPC Global developed Rapid Triaxial Tester (RaTT). The stress/load applied to the specimen is feed back controlled allowing the operator to select a loading wave shape (havesine or square pulse), the pulse width duration, the rest period before the application of the next pulse, the deviator stress/load to be applied during each loading pulse and the contact stress/load to be applied so that the vertical loading shaft does not lift off the test specimen during the rest period. Prior to testing a preload stress/load can also be programmed into the testing sequence. For controlled temperature testing, the specimen's skin and core temperatures are estimated by transducers inserted in a dummy specimen and located near the specimen under test.

3.3.6 Wheel Tracking Test

Wheel Tracking Test is used to determine the plastic deformation of asphalt based road surface wearing courses under temperature (normally is 45°C) and pressures similar to those experienced under road use. Such test can be carried out during road construction and also in laboratory. This test will prevent road surfaces being laid, which run in hot weather and need to be re-laid. The performance of the material is assessed by measuring the resultant rut depth after a given number of passes. The main equipment is Wessex Dry Wheel Tracker.

3.4 Safety Hazard

During the laboratory works, several safety hazards had been identified. Those safety hazards are as follows:

3.4.1 Accident Hazard

- Falls of heavy objects on head (from overhead storage shelves) and feet.
- Slips and falls on wet, uneven or damaged floors (esp. hazardous when hand-transporting dangerous materials, e.g. chemicals).
- Entanglement of clothes, hair, fingers, arms in rotating and other moving equipment, in particular centrifuges, mixers, blenders, etc.
- Electrocution and electric shock.
- Cuts and stabs from sharp edges.
- Fire and explosions in work with flammable gases, liquids and solids.
- Burns and scalds from flames, hot surfaces, hot gases and liquids

3.4.2 Ergonomic, Psychosocial and Organization factors.

- Musculoskeletal effects from routine work in a fixed position (esp. long time standing)
- Overexertion while moving or otherwise handling bulky and heavy pieces of equipment, package of chemicals, etc.
- Cumulative trauma disorders (CTD) as a result of repetitive manual operations, e.g., non-automated counting, manual polishing, etc.
- Psychological effect of "getting accustomed" to routinely encountered hazards with the resulting loss of alertness
- Problems associated with unusual working schedules (work at night, on holidays, etc.) required by the continuity of experiments or the need to tend animals

CHAPTER 4
RESULT/DISCUSSION

4.1 Aggregates Combined Grading

To achieve a smooth curve within specification limit, the following source of blended aggregate and bitumen grade 80 penetration are used together:

- Coarse Aggregates = 50 %
- Fine Aggregates = 45 %
- Filler = 5 %

Table 4.1 shows the percentage used of aggregates combined grading for the mix.

Table 4.1: Aggregates combined grading

Sieve Sizes (mm)	Percentage Used C.A 0.50	F.A 0.45	Filler 0.05	Total (%)	Specification Limits (%)
25.000	100.0	100.0	100.0	100.0	100
20.000	90.4	100.0	100.0	95.2	92 - 100
14.000	71.4	100.0	100.0	85.7	74 - 94
10.000	52.2	100.0	100.0	76.1	62 - 82
5.000	12.2	100.0	100.0	56.1	44 - 63
2.360	0.0	75.8	100.0	39.1	32 - 48
1.180	0.0	46.7	100.0	26.0	21 - 35
0.600	0.0	27.6	100.0	17.4	13 - 25
0.300	0.0	18.0	100.0	13.1	7 - 17
0.150	0.0	4.7	100.0	7.1	5 - 13
0.075	0.0	1.8	100.0	5.8	5 - 9

4.2 Particle Size Distribution Chart

Figure 4.1 shows the particle size distribution when plotted gives a smooth curve throughout the entire specifications limits of range sizes.

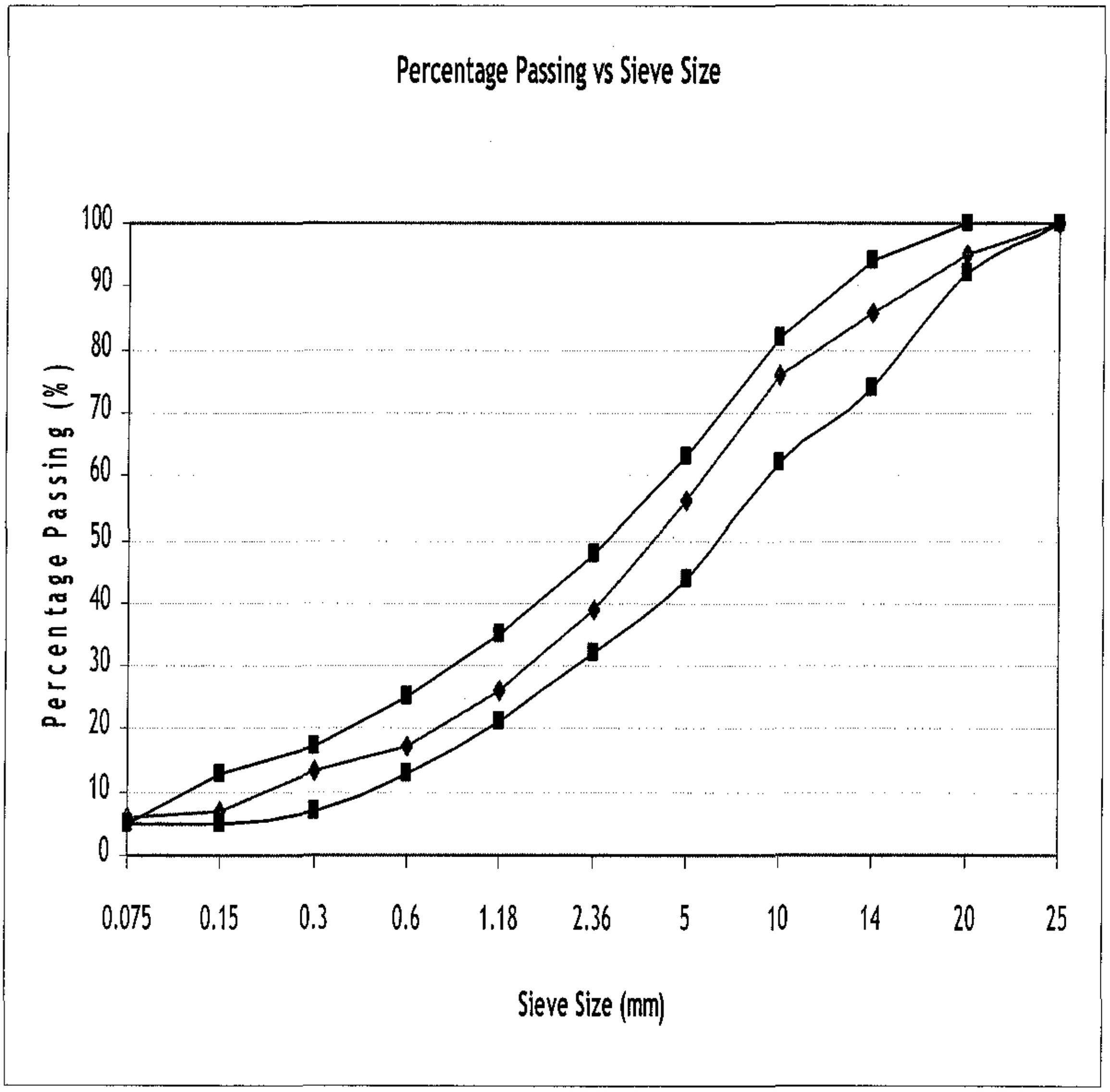

Figure 4.1: Aggregate Passing

4.3 Specific Gravity Test Using Ultrapycnometer 1000 Version 2.2

Based on the test, the results are as below:

- Specific Gravity Coarse Aggregates : 2.64
- Specific Gravity Fine Aggregates : 2.74
- Specific Gravity Cement : 3.26.
- Specific Gravity Iron Sludge : 4.33
- Specific Gravity Bitumen 80 : 1.03

Specific Gravity Aggregates for Control ACWC 20 Mix

$$\frac{P1+P2+P3}{\frac{P1}{SG1}+\frac{P2}{SG2}+\frac{P3}{SG3}} = \frac{50+45+5}{\frac{50}{2.46}+\frac{45}{2.74}+\frac{5}{3.2565}} = 2.71$$

Specific Gravity Aggregates for Iron Sludge as Filler ACWC 20 Mix

$$\frac{P1+P2+P3}{\frac{P1}{SG1}+\frac{P2}{SG2}+\frac{P3}{SG3}} = \frac{50+45+5}{\frac{50}{2.46}+\frac{45}{2.74}+\frac{5}{4.3296}} = 2.74$$

4.4 Scanning electron microscope (SEM)

Figure 4.2 shows that the results from the Scanning electron microscope (SEM) test results for Ordinary Portland Cement while figure 4.3 shows the results for iron sludge sample.

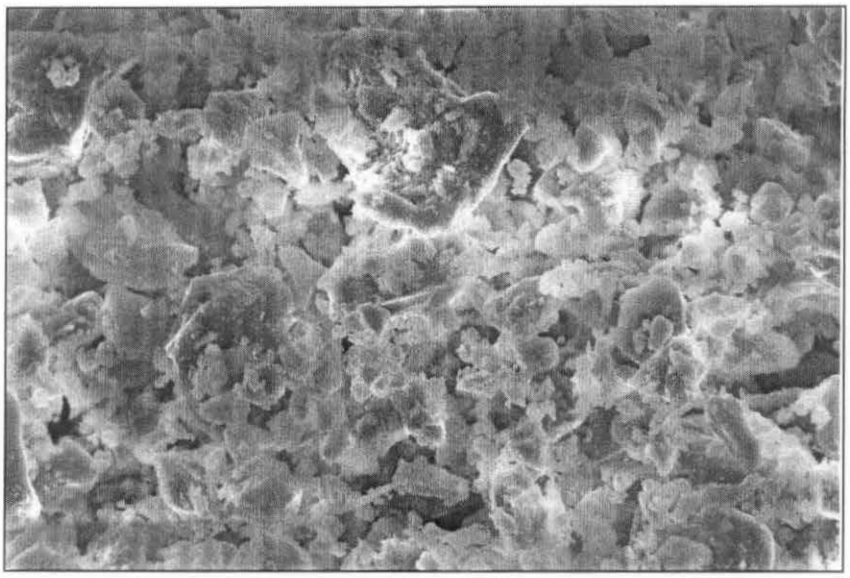

Figure 4.2: Ordinary Portland Cement

Figure 4.3: Iron Sludge

4.5 Marshall Test Result on Control ACWC 20 Mix

The maximum value for stability can be taken from Figure 4.4 that shows the behavior of stability in terms of bitumen content while the minimum value for VMA is shown on Figure 4.5.

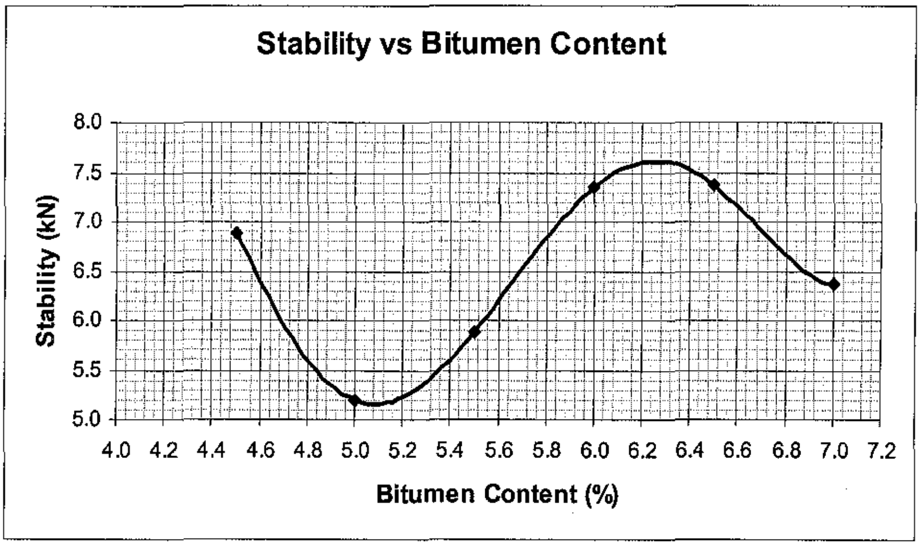

Figure 4.4: Stability for various bitumen content

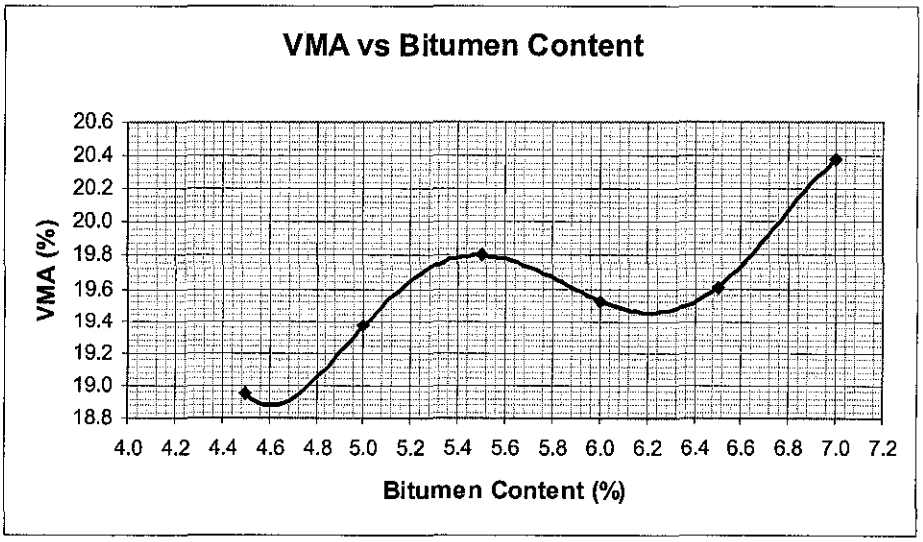

Figure 4.5: VMA for various bitumen content

The maximum value for density can be taken from Figure 4.6 that shows the behavior of density in terms of bitumen content while the optimum value for flow is shown on Figure 4.7.

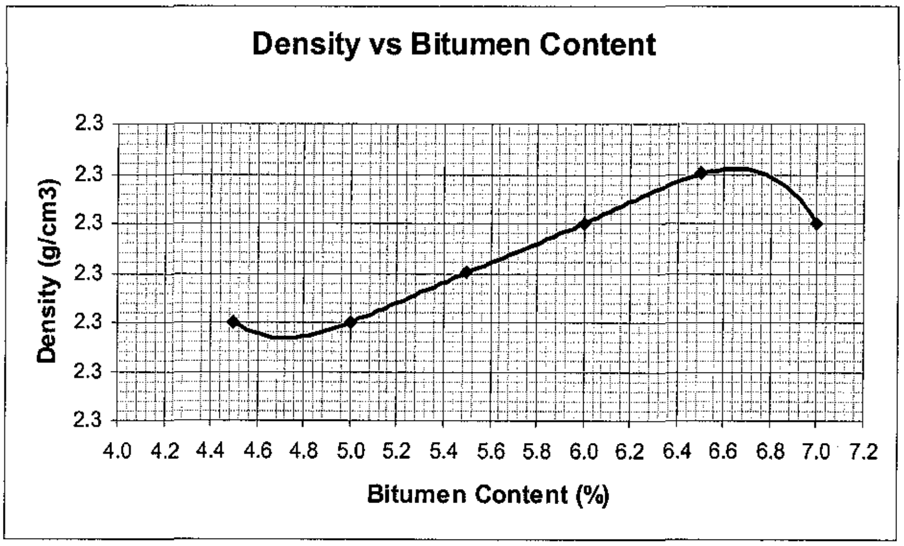

Figure 4.6: Stability for various bitumen content

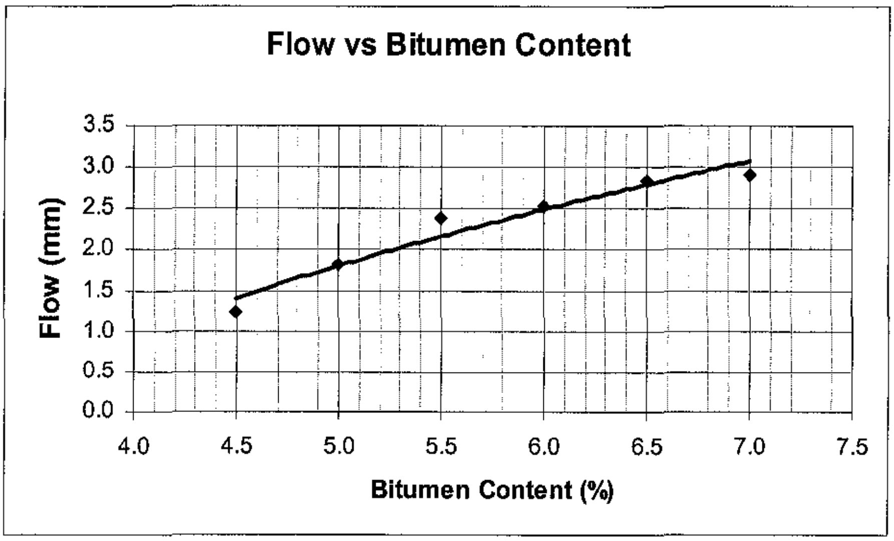

Figure 4.7: Flow for various bitumen content

The optimum value for porosity is shown on Figure 4.8. This to ensure that the value for porosity is according to the specifications.

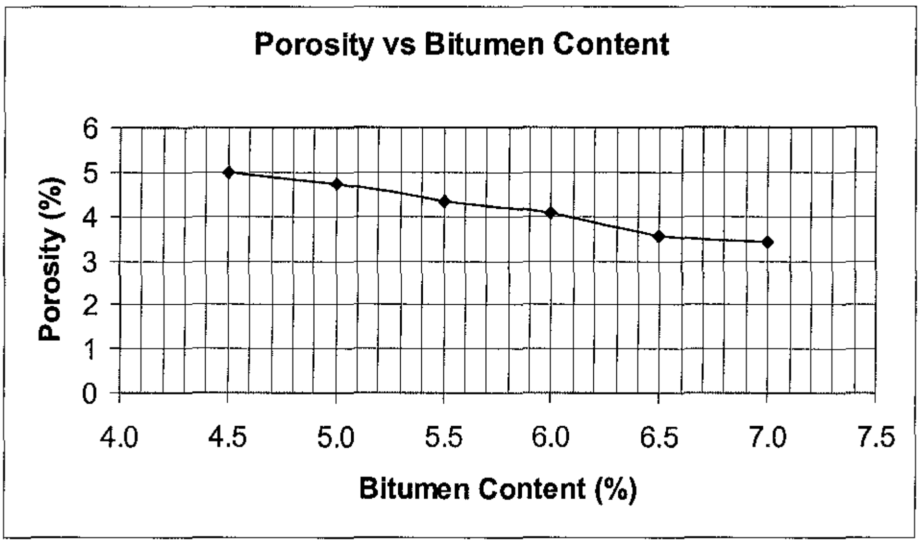

Figure 4.8: Flow for various bitumen content

Optimum Bitumen Content

$$\frac{6.3+4.6+6.68}{3}=5.9\%$$

Stability

$$\frac{7.37\times1000}{9.81}=7.51kg$$

Flow

Based on Flow vs Bitumen Content graph, for the OBC, the flow is 2.4 mm

Porosity

Based on Porosity vs Bitumen Content graph, for the OBC, the porosity is 4.0 %

Stiffness

$$\frac{Stability}{Flow} = \frac{751kg}{2.4mm} = 313kg/mm$$

Table 4.2 shows the summary of the Marshall Stability test results for standard mix.

Table 4.2: Characteristics of standard mix

Details	Specifications	Lab Result
Optimum Bitumen Content	4.5 % - 7 %	5.9 %
Stability	> 750 kg	751 kg
Flow	> 2 mm	2.4 mm
Stiffness	> 280 kg/mm	313 kg/mm
Voids In Total Mixture	3 % - 6 %	4 %

4.6 Marshall Test Result on Iron Sludge as Filler for ACWC 20 Mix

The maximum value for stability can be taken from Figure 4.9 that shows the behavior of stability in terms of bitumen content while the minimum value for VMA is shown on Figure 4.10.

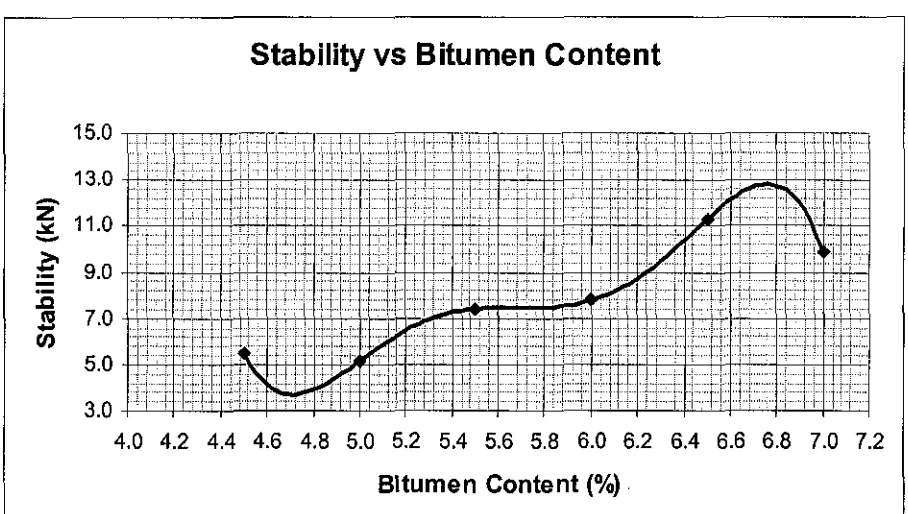

Figure 4.9: Stability for various bitumen content

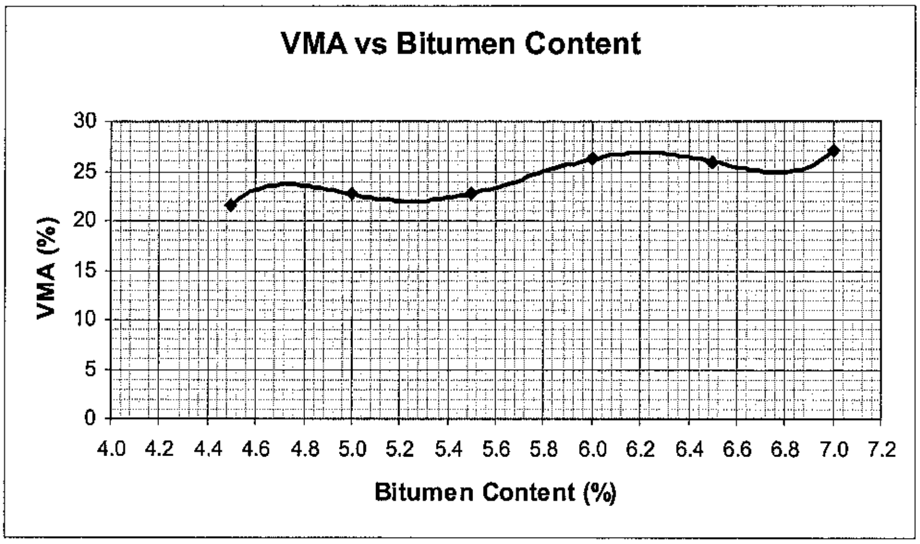

Figure 4.10: VMA for various bitumen content

The maximum value for density can be taken from figure 4.11 that shows the behavior of density in terms of bitumen content while the optimum value for flow is shown on figure 4.12.

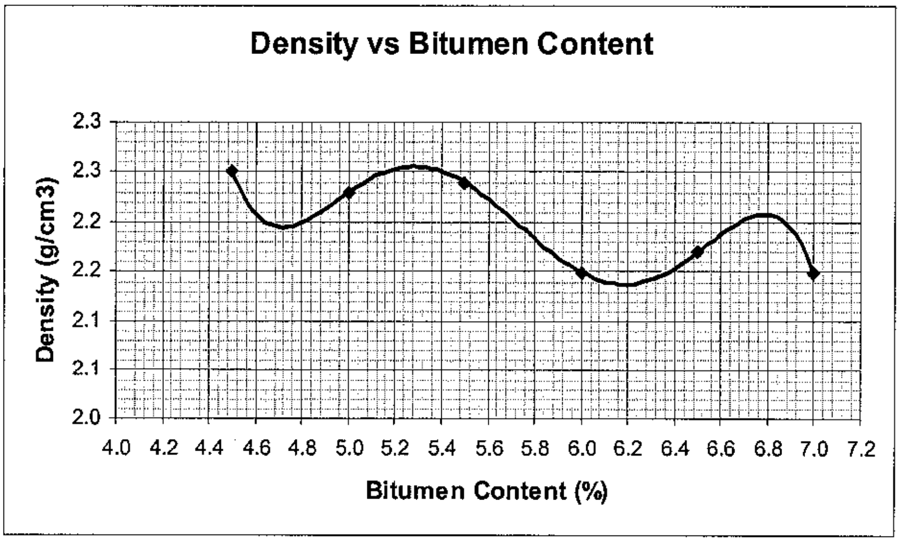

Figure 4.11: Stability for various bitumen content

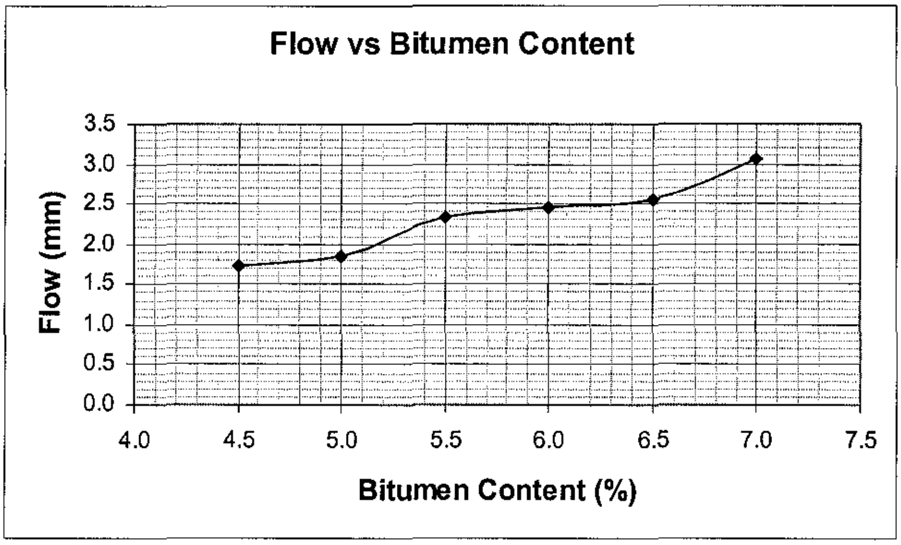

Figure 4.12: Flow for various bitumen content

The optimum value for porosity is shown on Figure 4.13. This to ensure that the value for porosity is according to the specifications.

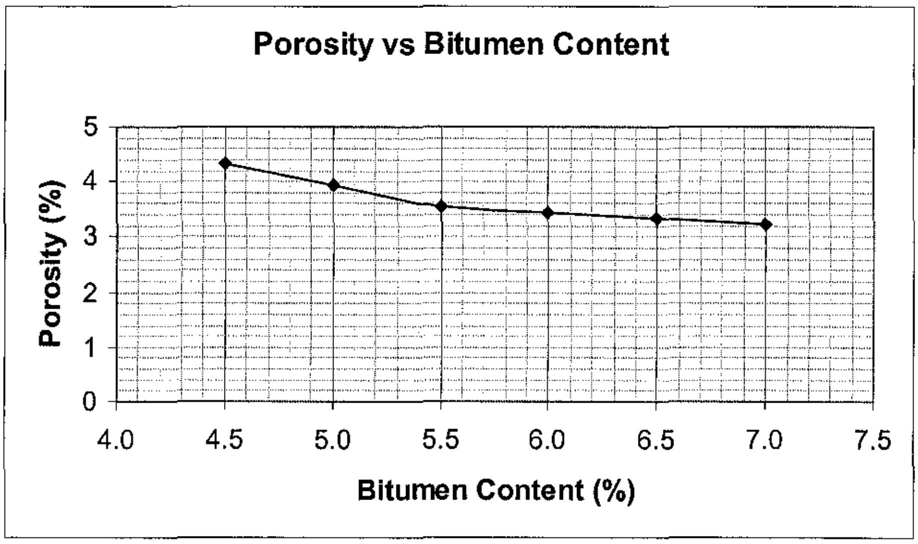

Figure 4.13: Porosity for various bitumen content

Optimum Bitumen Content

$$\frac{6.76+4.52+5.32}{3}=5.5\%$$

Stability

$$\frac{7.4\times1000}{9.81}=7.54kg$$

Flow

Based on Flow vs Bitumen Content graph, for the OBC, the Flow is 2.3 mm

Porosity

Based on Porosity vs Bitumen Content graph, for the OBC, the porosity is 3.5 %

Stiffness

$$\frac{Stability}{Flow}=\frac{754g}{2.3mm}=328kg/mm$$

Table 4.3 shows the summary of the Marshall Stability test results for modified mix.

Table 4.3: Characteristics of modified mix

Details	**Specifications**	**Lab Result**
Optimum Bitumen Content	4.5 % - 7 %	5.5 %
Stability	> 750 kg	754 kg
Flow	> 2 mm	2.3 mm
Stiffness	> 280 kg/mm	328 kg/mm
Voids In Total Mixture	3 % - 6 %	3.5 %

4.7 Beam Fatigue Test Result

The behaviors of the standard mix against fatigue are shown on Figure 4.14 while Figure 4.15 shows the behavior of fatigue for the modified mix.

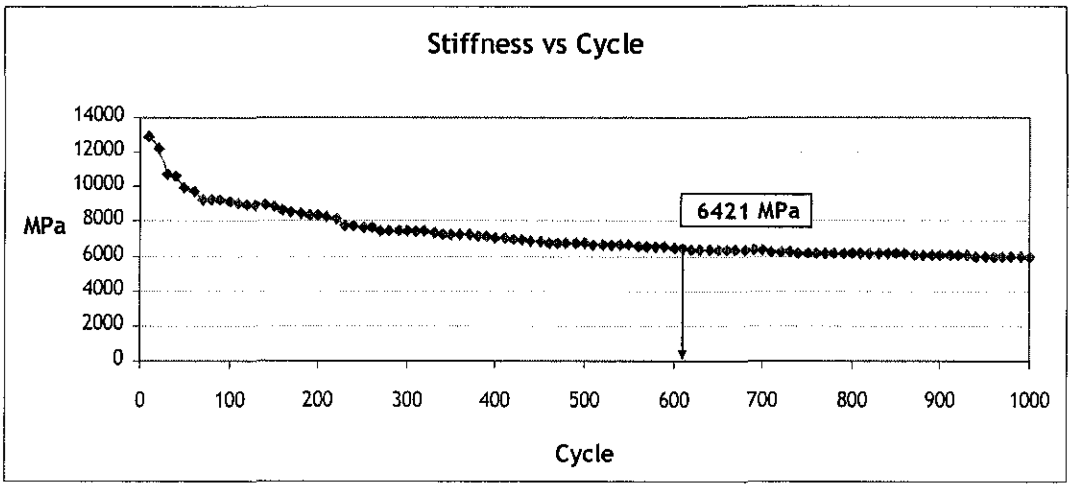

Figure 4.14: Fatigue behavior for standard mix

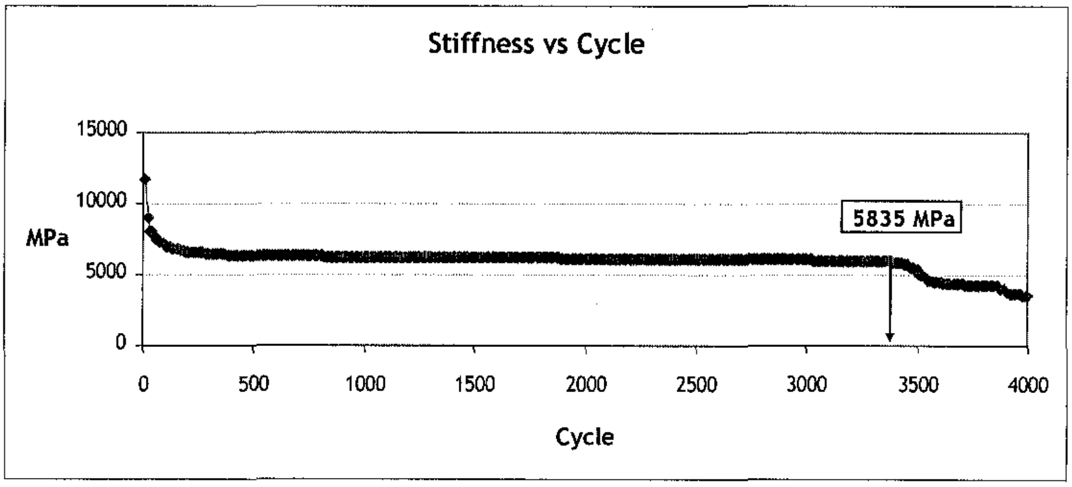

Figure 4.15: Fatigue behavior for modified mix

4.8 Dynamic Creep Test Result

The behavior of the standard mix against creep and rutting are shown on Figure 4.16 while Figure 4.17 shows the behavior of creep and rutting for the modified mix.

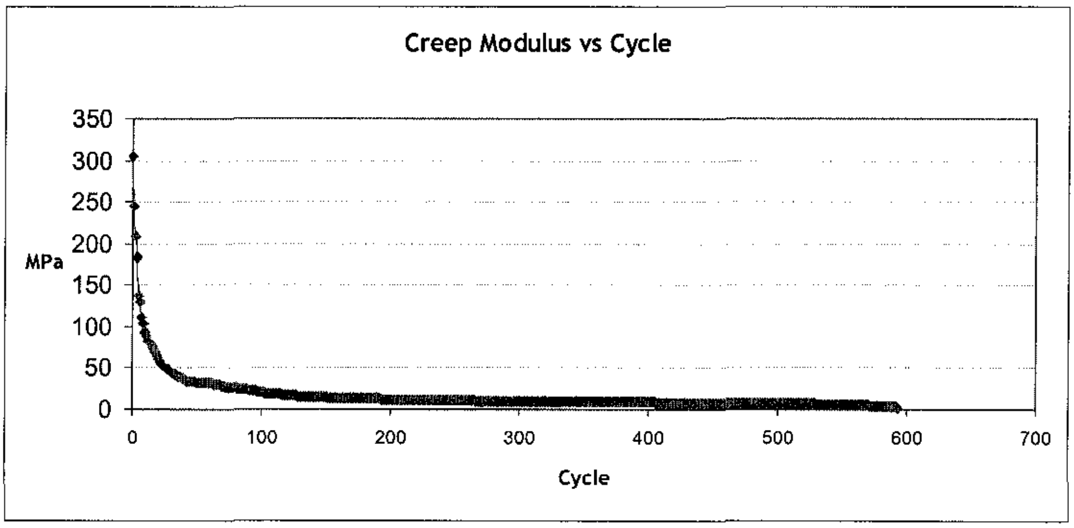

Figure 4.16: Creep behavior for standard mix

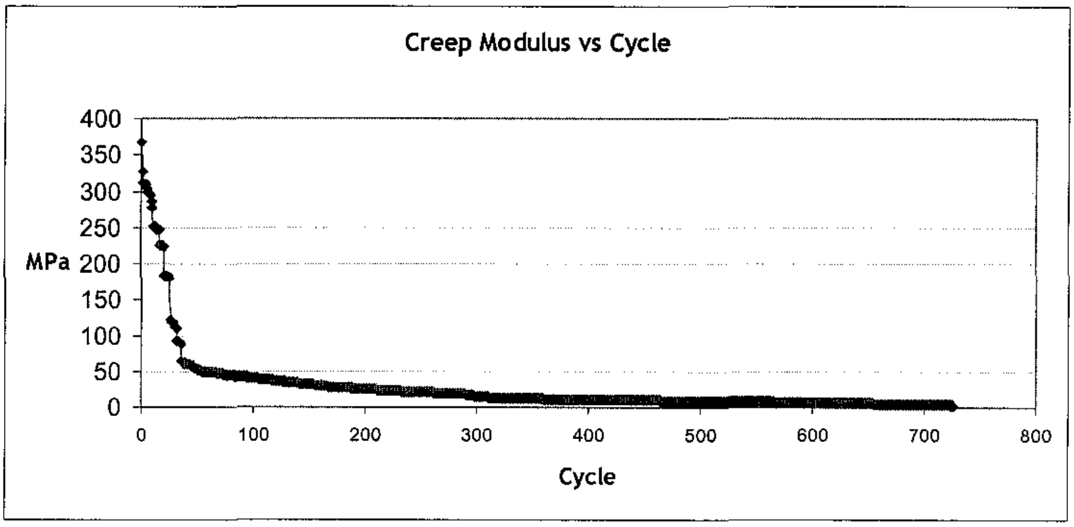

Figure 4.17: Creep behavior for modified mix

4.9 Wheel Tracking Test Result

The behavior of the standard and modified mix against deflection and rutting are shown on Figure 4.18.

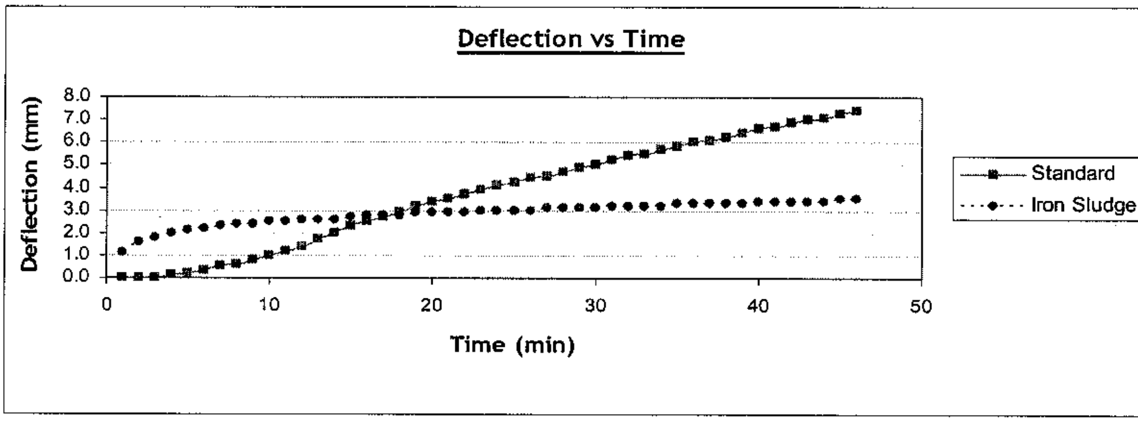

Figure 4.18: Deflection behavior for standard and modified mix

Deflection rate for standard mix = 0.1788 mm/min

Deflection rate for modified mix = 0.0369 mm/min

4.10 Discussion

Based on the Specific Gravity test results, it shows that the value of iron sludge is higher than Ordinary Portland Cement. It indicates that iron sludge is more compact and has less porosity compare to Ordinary Portland Cement.

According to the Scanning electron microscope (SEM) test, it shows that the voids in the iron sludge is lower than Ordinary Portland Cement. It indicates that iron sludge is more compact and has less porosity compare to Ordinary Portland Cement.

As for the results from Marshall Stability test, the modified mix managed to achieve higher performance than the standard mix. The optimum bitumen content for modified mix is lesser than the standard mix which indicates less bitumen content are needed for the modified mix. Value for stiffness for modified mix is higher than standard mix and it shows that the modified mix is more rigid and stronger than the standard mix. The voids in total mixture also lesser for the modified mix and it point out that the porosity in modified mix is lesser and achieved higher compaction compare to standard mix.

According to the Beam Fatigue results, it shows that the modified mix needed longer time to reach the half of its initial stiffness compare to the standard mix. It indicates that the modified mix has longer fatigue life and more durable against crocodile cracking.

Based on the Dynamic Creep test results, it shows that the modified mix took longer time to reach the failure point compare to the standard mix. It indicates that the modified mix has better performance against rutting effect.

Based on the Wheel Tracking test results, it shows that the modified mix has lower rate of deflection compare to the standard mix. It indicates that the modified mix has better performance against rutting effect.

CHAPTER 5
CONCLUSION & RECOMMENDATION

5.1 Conclusion

As for the results from Marshall Stability test, the modified mix managed to achieve higher performance than the standard mix. The optimum bitumen content for modified mix is 0.4 % lesser than the standard mix which indicates less bitumen content are needed for the modified mix. Value for stiffness for modified mix is 5 % higher than standard mix and it shows that the modified mix is more rigid and stronger than the standard mix. The voids in total mixture also 0.5 % lesser for the modified mix and it point out that the porosity in modified mix is lesser and achieved higher compaction compare to standard mix. The stability also higher as compared to the standard mix. According to the Beam Fatigue results, it shows that the modified mix needed longer period which about five times more to reach the half of its initial stiffness as compared to the standard mix. It indicates that the modified mix has longer fatigue life and more durable against crocodile cracking. Based on the Dynamic Creep test results, it shows that the modified mix took longer time to reach the failure point which about 22 % as compared to the standard mix. It indicates that the modified mix has better performance against rutting effect. Based on the Wheel Tracking test results, it shows that the modified mix has lower rate of deflection which about four times more as compared to the standard mix. It satisfies that the modified mix has better performance against rutting effect. It can be concluded that the ACWC 20 mix that was using iron sludge as filler has complied with the specification and not just achieved the performance of the conventional ACWC 20 mix but also has obtained better performance.

5.2 Recommendation

It would be better if the mix that is using iron sludge as filler could be laid on site for about a year or more so that the performance of the laid pavement could be analyze for further studies.

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