CERTIFICATION OF APPROVAL

WATER SUSCEPTIBILITY CHARACTERISTICS OF GEOPOLYMER BITUMINOUS MIXTURE

By

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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.

AMEER MUSTAKIM ABADI

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ABSTRACT

This final report is produce to compile the findings of the project entitled 'Water Susceptibility Characteristics of Geopolymer Bituminous Mixture' for Final Year Project 2. This report contains project background, problem statement, objective & scope of study, literature review, methodology, result & discussion and also conclusion & recommendation section.

Geopolymer bituminous mixture is a new finding that can replace the normal conventional bituminous mixture because it is higher in strength. It is a mixture which has strengthens by geopolymer slurry and proved its strength by Marshall Test. This project is to affirm the findings with the study on one of its performance which is the water susceptibility.

The test needs to be conducted in order to understand how this material could resist one of the major failures in pavement that is stripping. Hence this project will assist us to get more information on the reaction of the presence of water to this mixture. Besides, we also can make comparison between geopolymer bituminous mixtures with the normal pavement in terms of moisture susceptibility.

Therefore, this report will explain on the mechanism of moisture damage, factors that influence the damages, stripping & debonding process, properties of water, lists of laboratory tests (qualitative & quantitative) that can be apply to achieve the objective, result and discussion gained from the test. Finally, we compare and conclude the overall findings on this study.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Last semester, the Final Year Project (FYP) on 'The Uses of Geopolymer in Porous Asphalt' has been done successfully by Universiti Teknologi Petronas (UTP) student. The project is on porous asphalt pavement that strengthens using geo-polymer (in slurry condition).

Geo-polymer is produced by the reaction between alkaline solution and aluminosilicate. The alkaline solution had been used is NaOH and Na2SiO3, while the aluminosilicate used is fly ash. Fly ash refers to ash that produced during combustion of coal. The reaction between these 2 components will produce very early high strength cement.

Figure 1.1: Geopolymer Bituminous Mixture

Marshall Test has been applied to obtain the sample strength to compare both porous asphalt with geopolymer and normal conventional pavement. Based on the test, it is proved that sample of porous asphalt with geopolymer have higher strength compared to normal conventional road pavement. Besides, the design is economically effective and environmental friendly as it utilized natural sources.

There are some other properties that we need to obtain from this mixture. For this project, it will focus on water susceptibility test. From the research, it seems the moisture susceptibility is one of the most important parameter to know as it occur damages on pavement called stripping.

1.2 PROBLEM STATEMENT

The presence of water or moisture is the main cause of failure in a finished bituminous mix pavement. It will cause the binder to not adhere to the aggregate. Since the binder react as the glue that hold the aggregate and bitumen, it will produce failure toward the pavement if the glue cannot hold them anymore.

Moisture susceptibility is a measure of how susceptible a bituminous mixture's internal asphalt binder-to-aggregate bond (cohesion) is to weakening in the presence of water. Results from the moisture susceptibility test may be used to predict long-term stripping susceptibility of bituminous mixtures and to evaluate anti-stripping additives, which are added to the asphalt binder, aggregate, or bituminous mixture.

Hence, by doing this project we can determine the water susceptibility characteristic for the geopolymer bituminous mixture in order to figure out the properties in the presence of water.

1.3 OBJECTIVE & SCOPE OF STUDY

The main objective of this project is to determine the performance characteristic of geopolymer bituminous mixture which is water susceptibility. The comparison of water susceptibility in conditioned geopolymer bituminous mixes with unconditioned mixes need to be done in order to see which mixture is in high performance.

The study is initially done by doing some research on the project journals and laboratory test method that related to the topic. All the needed information will then be extract to give more understanding on this topic. In other hand, more comparison of from different perspectives and method used to obtain the water susceptibility of the material can be done.

After enough information gathered, then laboratory experiments will be conducted. The tests or experiments are to evaluate the water susceptibility practically. Then the result and data that gained from the tests will be recorded and do the conclusion.

CHAPTER 2

LITERATURE REVIEW

2.1 GEOPOLYMER MIXTURE

Based on previous study, geo-polymer is produced by the reaction between alkaline solution and aluminosilicate. In this project, alkaline solution that had been used is NaOH and Na2SiO3, while the aluminosilicate than been used is fly ash. The reaction between these 2 components will produce very early high strength cement.

Fly ash is one of the residues generated in combustion, and comprises the fine particles that rise with the flue gases. Fly ash refers to ash produced during combustion of coal.

2.2 POROUS ASPHALT

Porous asphalt is special wearing course that used in pavements that requiring improved surface drainage and skid resistance. It is produced using open-graded aggregate mixed with polymer modified binder which contains air voids of 20 to 25% after compaction. Porous asphalt is laid on impermeable and even bituminous surface with adequate cross fall of at least 2.5% for the sub-surface drainage. It is necessary that existing cracks and depression be sealed and patched prior to application of porous asphalt.

According to Specification for Porous Asphalt, by Road Engineering Association of Malaysia collaboration with Jabatan Kerja Raya (JKR) the materials used for porous asphalt is such below:

Coarse Aggregate

The coarse aggregate used shall be screened crushed rock, angular in shape and free from dust, clay, vegetative, organic matter, and other deleterious substances. They shall conform to the following physical and mechanical quality requirements:

a) The loss by abrasion and impact in the Los Angeles machine when tested in accordance with ASTM C 131 shall be not more than 25%.

b) The weighted average loss of weight in the magnesium sulfate soundness test (five cycles) when tested in accordance with AASHTO T 104 shall be not more than 18%

c) The flakiness index when tested in accordance with MS 30 shall be not more than 25%

d) The water absorption when tested in accordance with MS 30 shall be not more than 2%

e) The polished stone value when tested in accordance with MS 30 shall be not less than 40.

Notwithstanding compliance with the aforementioned requirements, crushed or uncrushed limestone and gravel shall not be permitted.

Fine Aggregate

The fine aggregate shall be screened quarry fines. They shall be non-plastic and free from clay, loam, aggregations of material, vegetative and other organic matter or deleterious substances. They shall conform to the following physical and mechanical quality requirements:

a) The sand equivalent of aggregate fraction passing the No.4 (4.75mm) sieve when tested in accordance with ASTM D 2419 shall be not less than 45%

b) The fine aggregate angularity when tested in accordance with Ohio Department of Transportation Standard Test Method shall be not more than 10mg/g

c) The weighted average loss of weight in the magnesium sulfate soundness test (five cycles) when tested in accordance with AASHTO T 104 shall be not more than 20%

d) The water absorption when tested in accordance with MS 30 shall be not more than 2%

Mineral Filler

Mineral filler shall be incorporated as part of the combined aggregate gradation and it shall be of finely divided mineral matter of hydrated lime (calcium hydroxide). At the time of mixing with bitumen, the hydrated lime shall be not less than 70% by weight shall pass the BS 75 µm sieve. If hydrated lime is not available, ordinary Portland Cement shall be used as alternative, subject to approval by the S.O. the amount of mineral filler to be added shall be not less than 2% by weight of the combined aggregates. However, the amount shall be limited to not more than 2% if hydrated lime is used.

Bituminous Binder

The bituminous binder for use with porous asphalt shall be of performance grade PG 76 or higher incompliance with AASHTO Standard M320-02

Gradation of Combined Aggregates.

The gradation of the combined coarse and fine aggregates, together with at least 2% mineral filler, shall conform to the appropriate envelope as given:

BS Sieve Size, mm	Percentage Passing, by weight	
	Grading A	Grading B
20.0	-	100
14.0	100	85-100
10.0	95-100	55-75
5.0	30-50	10-25
2.36	5-15	5-10
0.075	2-5	2-4

Table 2.2: Gradation of Combined Aggregate

Porous Asphalt Mix Design

With high air voids and open-graded aggregates, high binder contents are essential to ensure mix integrity, increase resistance to oxidation, raveling and improve durability. The quantity of binder shall be carefully balanced such that it is not deemed to excessive to cause binder drain-down during production, transport and laying or deemed too little to adversely affect durability.

Laboratory Compacted Specimen

Porous Asphalt mixes shall be compacted in the laboratory by using the Marshall method, in accordance with ASTM D 1559. The specimens shall then be used for further analysis as described hereof.

Because of the limited compactive effort applied in the field on porous asphalt mixes, the number of blows per face shall be 50.

Air Voids Requirement

The design and in-place air voids shall be in the range of 18 to 25%

2.3 MOISTURE DAMAGE

Moisture damage in bituminous pavements occurs because water enters the asphalt mixture and causes loss of adhesion at the binder/aggregate interface (Bagampadde, 2005). Some claims that moisture damage happens due to water weaken the binder by reducing its stiffness. Previously, the area of moisture damage has attained much attention through research. But, its theories and causative mechanisms still are complex and difficult from being fully understood.

According to most publications, moisture damage is associated with bitumen properties, aggregate characteristics, hot mix processing, bituminous mixture type and characteristics, environment and methods of construction, nature of water that displaces the binder, dynamic effect of traffic loading, type and properties of anti-stripping additives, and others.

Figure 2.3: The different between two tested specimens. *Bituminous having moisture damage (left) and the one with damage (right). The different is the amount of uncoated of aggregate.*

The mechanisms of moisture damage are as follow:

- **Chemical.** Chemical adhesion caused by chemical reaction between the asphalt binder and aggregate surface happen. Generally, aggregates with acidic surfaces not reacting strongly with asphalt binders. Therefore they cannot counter the damage because of this weaker reaction.
- **Mechanical.** The mechanical lock is produced when asphalt binder gets into the surface irregularities and pores of the aggregate and hardens. Water on the aggregate can interfere with asphalt binder penetration into the aggregate and tends to decrease the mechanical lock, thus could increase the susceptibility.
- **Adhesion tension.** The tension between asphalt binder and aggregate, at the wetting line (wetting line is the edge of a drop spreads over a surface) generally less than the tension between water and aggregate. When all these components are in contact, water will tend to displace asphalt binder. This will produce poor wetting of the aggregate surface by the asphalt binder and lead to stripping. The interfacial tension between asphalt binder and aggregate is varies with aggregate type, asphalt binder type, and surface roughness of aggregates.
- **Molecular orientation.** When asphalt molecules in contact with aggregate, they tend to orient themselves in relation to the ions on the aggregate surface essentially generates a weak attraction between the asphalt binder and aggregate surface. If water molecules, which are dipolar, are more polar than asphalt binder molecules, they may preferentially satisfy the energy demands of the aggregate surface. This will result the stripping failure.

2.4 FACTORS INFLUENCING MOISTURE DAMAGE

Moisture susceptibility is a complex phenomenon that depends on the discussed mechanisms in previous topic. The nature of the mechanisms and their interaction makes it difficult to predict whether a particular characteristic will be the overriding factor in determining moisture susceptibility. Regularly, moisture susceptibility is increased by any factor that increases moisture content in the bituminous mixture, decreases the adhesion of asphalt binder to the aggregate surface or physically scours the asphalt binder. Below are the factors that influence the moisture damage but no single one is a perfect standard for predicting moisture susceptibility.

- **Asphalt binder characteristics.** Viscosity indicates higher concentrations of asphaltenes (large polar molecules). Polar molecules can create greater adhesion tension and molecular orientation adhesion. Therefore, lower viscosities, which may represent lower concentrations of asphaltenes, are generally more susceptible to stripping. Individual components in asphalt binder such as sulfoxides, carboxylic acids, phenols and nitrogen bases can also affect stripping potential.

- **Aggregate characteristics.** In most cases, aggregates that are hydrophilic (attract water) and more likely to strip than aggregates that are hydrophobic (repulse water). The key aggregate properties that determine this hydrophilic/hydrophobic characteristic are:
    - *Surface chemistry.* Surfaces that can more readily form bonds with the asphalt binder are less likely to cause stripping. In general, a more acidic aggregate surface is more susceptible to stripping. Iron, magnesium, calcium and perhaps aluminum are considered beneficial, while sodium and potassium are considered detrimental (Hicks, 1991).
    - *Porosity and pore size.* Pore size is the critical factor. If pores are large enough to allow asphalt binder entry, they may be a contributor to moisture susceptibility. High porosity results in high absorption, which means that more asphalt binder, must be used to achieve the desired

effective asphalt binder content. Conversely, if high porosity is not considered, for a given amount of asphalt binder, more will be absorbed and less will be available to create the asphalt binder film around aggregate particles causing faster aging and possibly stripping.

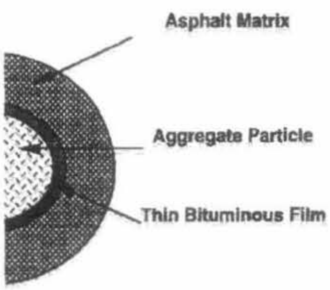
- **Construction weather.** Cool weather construction can lead to insufficient compaction, resulting in high air voids and a relatively permeable HMA pavement. This increases the likelihood of water in the pavement structure and thus, moisture damage. Wet weather can also increase the moisture content in the constructed HMA.

- **Climate.** Wetter climates, freeze-thaw cycles and temperature fluctuations can all allow more moisture into the HMA structure thus increasing the likelihood of moisture damage.

- **Traffic.** If water is present in the HMA structure, increased traffic loading can accelerate moisture damage for 2 reasons:
    - *Pore pressure buildup.* If water is in the aggregate pores and cannot escape, traffic loading will tend to compress these pores and cause a pressure buildup, which could push asphalt binder away from the aggregate surface.
    - *Hydraulic scouring.* Wheel passes over a HMA pavement tend to move water in the pavement. This movement causes a scouring action that could remove asphalt binder from the aggregate surface.

2.5 STRIPPING & DEBONDING

Debonding (stripping) is defined as the physical separation of asphalt cement and aggregate produced by adhesion failure (Majiidzadeh et al. 1968; Lottman et al. 1971). It is a complex problem that depending on many reliable, including the type and use of mix, asphalt characteristics, aggregate characteristics, environment, traffic, construction practice and the use of anti strip additives; however moisture is the common factor to all stripping. Debonding, as described, may be understood as the separation between the thin bituminous film, formed during the mixing stage at elevated temperatures, and the aggregate particle.



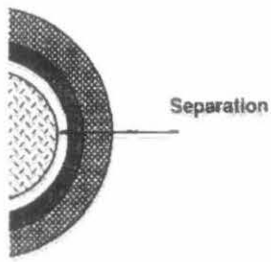


Figure 2.5 a: Before Debonding *Figure 2.5 b: After Debonding*

Figure 2.5 c: Stripping on pavement

2.6 EFFECT OF WATER IN BITUMINOUS MIXTURE

Water exhibits hydrogen bonds that affect its adhesive and cohesive characteristics. Since aggregate surfaces have electrostatic charges, water molecules are attracted to them with stronger forces than bitumen components to satisfy unbalanced surface charges (Bagampadde, 2005). According to Scott (1978) and Yoon et al. (1988), adhesion is thought to be influenced by changes in pH of contact water, which itself changes with temperature and type of aggregate. They showed that water susceptibility of the hydrogen bonds and salt links at the interface would increase with pH of the water at the aggregate surface. Nevertheless, their results showed that this did not hold for salts resulting from association of alkaline earth metals (like calcium) and bitumen carboxylic acids.

CHAPTER 3

METHODOLOGY

3.1 FLOW OF WORK

In order to complete this project, it must be organize well and the planned the work flow as the figure shown below.

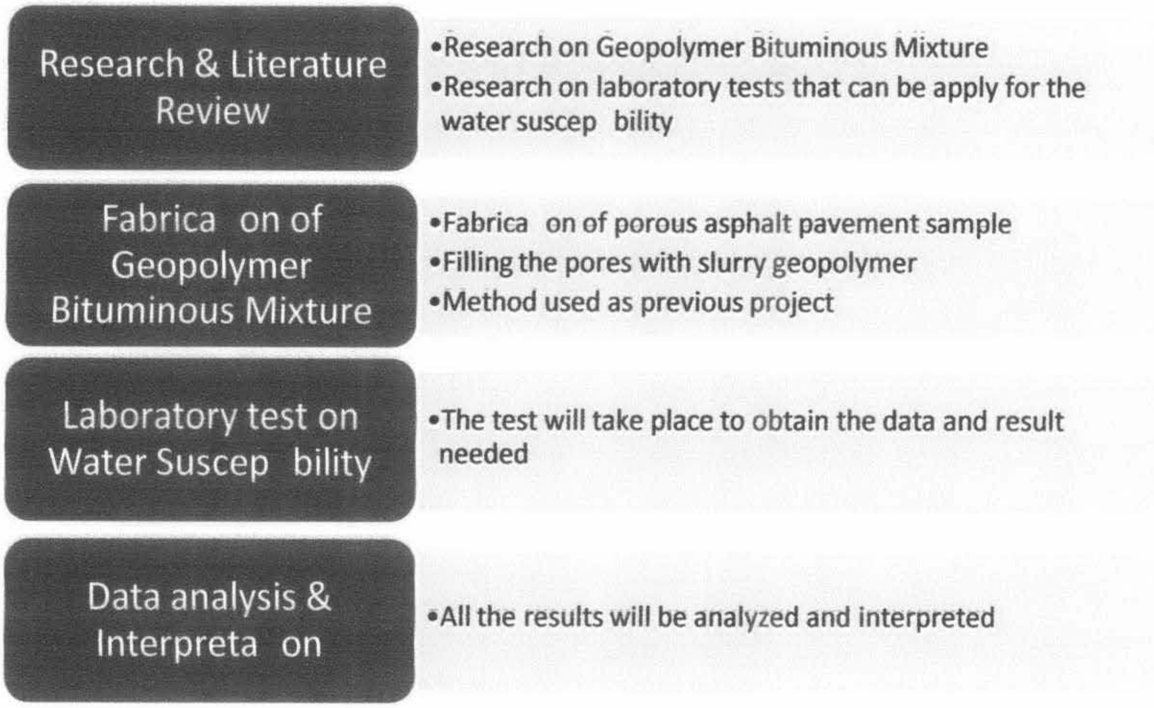


Figure 3.1 Flow of work

3.2 STUDY OF LABORATORY TESTS

In order to determine the moisture susceptibility, laboratory test must be done. Generally, moisture susceptibility tests do not measure individual factors but rather attempt to quantify a bituminous mixture's ability to resist moisture damage. Kandhal (1994) stated that no test has proven "superior" at correctly identifying a moisture-susceptibility mix in all cases. This is because they have low reliability and lack a satisfactory relationship between laboratory and field conditions. The tests are divided into Qualitative or Subjective Tests and Quantitative Strength Tests.

3.2.1 Qualitative or Subjective Tests

Boiling test (ASTM D 3625). Loose HMA mix is added to boiling water (most agencies use 10 min boiling period) and measure the percentage of total visible area of aggregate surface that retains its asphalt binder coating. The test is simple but is subjective, does not involve any strength determination and examining the fine aggregate is difficult. Some agencies use this type of test for the quality control during production to determine the presence of antistripping agent.

Static-Immersion Test (AASHTO T 182). HMA sample is immersed in distilled water for 16 to 18 hours at 25°C (77°F) and then observed through the water to measure the percentage of total visible area of aggregate surface that retains its asphalt binder coating. This test is also simple but subjective and does not involve any strength determination.

3.2.2 Quantitative Strength Tests

i) Lottman test (NCHRP 246).

This test was developed by Lottman (1982) under National Cooperative Highway Research Program 246. 3 sets of compacted samples (102mm diameter 64mm thickness) that contain of 3 specimens are tested. Group 1, the control group, is not conditioned. Group 2, representing field performance at 4 years, is subjected to vacuum saturation with water (660 mm or 26 in.Hg) for 30 min. Group 3, representing field performance at 4 to 12 years, is subjected to vacuum saturation like Group 2 and a freeze (-18°C for 15 hour)-thaw (60°C) cycle. A split tensile test is performed on each sample and the ratio of the indirect tensile strength of the conditioned samples is compared to the control group as a ratio. The Indirect Tensile Strength (ITS) at 13°C or 23°C, loading rate of 1.65 mm/min. A minimum tensile strength ratio (TSR) of 0.70 to 0.80 is often used as a standard.

Tensile strength is calculated using formula:

$$S_t = \frac{2P}{\pi t D}$$

Where:

- St = tensile strength (psi)
- P = maximum load (lbs)
- t = sample thickness (inches)
- D = sample diameter (inches)

Retained Tensile Strength Ratio (TSR) $= \frac{\text{ITS of conditioned specimens}}{\text{ITS of control specimens}}$

ii) Tunnicliff and Root Conditioning (NCHRP 274).

It was proposed by Tunnicliff et al (1984) for NCHRP project 274. The test is almost same to the Lottman test but, this it uses only 2 groups of specimens and eliminates the freeze-thaw group. Group 1 are treated as a control, without conditioning. Group 2 are vacuum-saturated at 508 mm or 20 in. Hg for 5 min with water to attain a saturation level of 55 to 80%. The specimens that attain more than 80 percent saturation are discarded. The saturated specimens are then soaked in water at 60°C for 24 hours. All specimens are tested for ITS at 25 °C using a loading rate of 51 mm/min. A minimum TSR of 0.7 to 0.8 usually specified.

iii) Modified Lottman (AASHTO T 283).

This method was proposed by Kandhal (1986) and adopted by AASHTO. This method combined the Lottman (NCHRP 246) and Tunnicliff and Root test (NCHRP 274). 6 specimens divided to 2 group are compacted to a 6 to 8 percent air-void content. Group 1 is used as control. Group 2 are vacuum saturated (55-80 percent saturation) with water and then subjected to one freeze and thaw cycle as proposed by Lottman. All specimens are tested for ITS at 25°C using a loading rate of 51 mm/min and the TSR is determined. A minimum TSR of 0.7 is usually specified. This method is gaining acceptance by the specifying agencies.

iv) Immersion-Compression Test (AASHTO T 165).

Six specimens (102mm diameter and 102mm thickness) are compacted with double plunger at a pressure of 20.7 MPa (3000 psi) for 2 min to about 6 percent air-void content. Group 1 (3 samples) is treated as control. Group 2 are placed in water at 49°C for 4 days or at 60°C at 1 day. All specimens are tested for unconfined compressive strength at 25°C using 5.1 mm/min loading rate. The retained compressive strength is determined. Many agencies specify at least 70 percent retained strength but it produce nearly 100 percent, even when stripping is evident. Lack of precision is a major problem with this test.

v) Retained Stability Test

This test measures the stripping resistance of a bituminous mixture. The test is specified in IRC: SP 53-2002 on modified binders and is conducted as per ASTM D 1075-1979 specifications. The standard Marshall specimens if 100 mm diameter and 63.5 mm height were prepared. The specimens were kept in water bath maintained at 60°C for 24 hours, and thereafter tested for stability value. The results are reported as the percentage of Marshall stability determined in normal condition of the test.

3.2.3 Rate of Successful On Laboratory Test

All of these tests have weaknesses that result in an ongoing search for a better moisture susceptibility test. These weaknesses, in addition to the ones discussed above, tend to be issues with repeatability and reproducibility of test results and questionable predictive ability. Also, small variations in key HMA parameters such as air voids (Va), can substantially affect test results. According to Kiggundu et al (1988) the success rate of several tests, based on test data available from various research report and papers as given in Table 3.2.3.

Test Method	Minimum Test Criteria	% Success
Modified Lottman (AASHTO T283)	TSR = 70%	67
	TSR = 80%	76
Tunnicliff-Root (ASTM D4867)	TSR = 70%	60
	TSR = 80%	67
	TSR = 70-80%	67
10-Minute Boil Test	Retained Coating 85-90%	58
Immersion-Compression (AASHTO T165)	Retained Strength 75%	47

Table 3.2.3: Success Rates of Test Method

3.3 GANTT CHART

No	Activities	Semester May 2011				Semester Sep 2011			
		Month				Month			
		May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	Selection of project topic								
2	Submission of project proposal								
3	Literature review research								
4	Project work								
5	Submission of progress report								
6	Project work continues								
7	Submission of interim report								
8	Data completion for first stage								
9	Oral Presentation								
10	Project work continue								
11	Submission of progress report II								
12	Project work continue								
13	Submission of final dissertation draft								
14	Poster presentation								
15	Submission of final report								

CHAPTER 4

LABORATORY WORK & TEST

4.1 SAMPLE PREPARATION

The sample was done by taking into account the previous study of the geopolymer bituminous mix. For the porous asphalt, JKR specification for a single Marshall sample needed for aggregate, filler and bitumen are:

BS Sieve Size, mm	Percentage Retained	Weight (g)
20.0	-	-
14.0	7.5	90
10.0	27.5	330
5.0	47.5	570
2.36	10.0	120
0.075	4.5	54
TOTAL	97	1164

Table 4.1: Porous Asphalt Specs

The remaining 3% or 36 g is for filler (OPC).

From previous study, the optimum bitumen content used is 5% and its grade is 80/100.

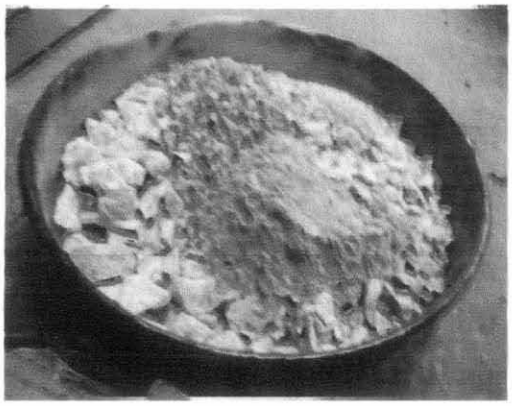


Figure 4.1.1: Sample preparation *Figure 4.1.2: Bitumen (80/100)*

The samples need to be dry in oven about 24 hours to ensure there is no moisture within the aggregates or sands. After that, the mixing process will take place. The bitumen will pour inside the mixer together with the aggregates, sands and filler (the temperature is 160 °C).

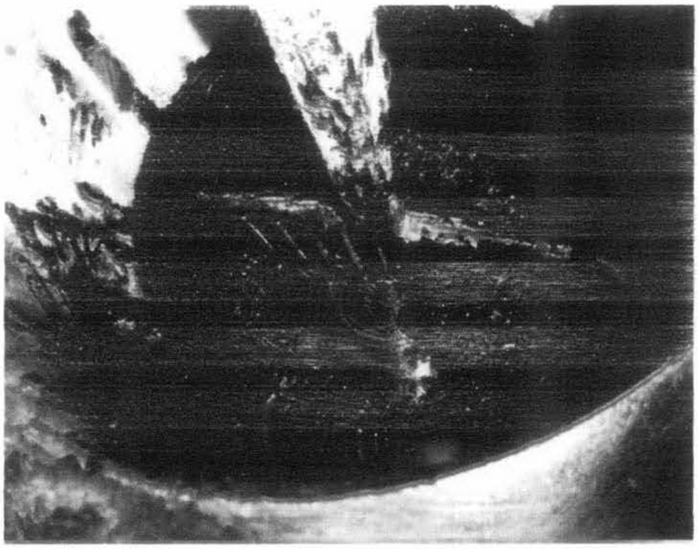


Figure 4.1.3: Sample during mixing

When the mixture is well-mixed, they were pour into the mould to be compacted both surfaces (top and bottom sides). The compaction needs 75 blown each surface that indicates the high traffic condition.

Figure 4.1.4: Compaction process

After the compaction process is completed, the sample was taken out from the mould and being left to the room temperature.

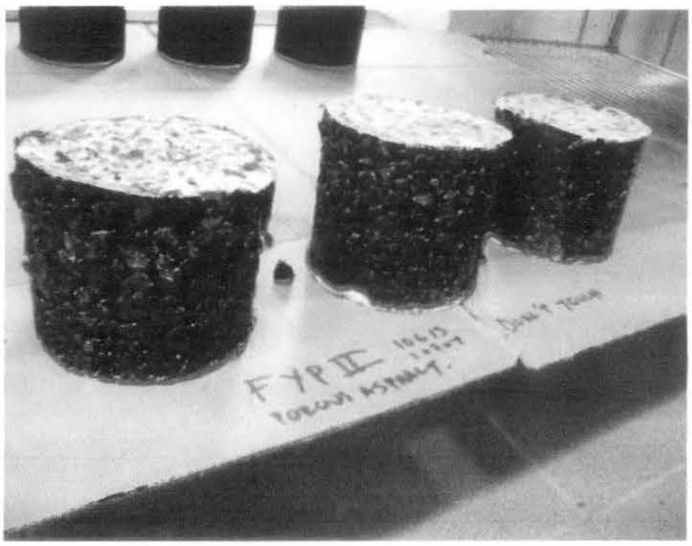


Figure 4.1.5: Completed samples

4.2 GEOPOLYMER PREPARATION

The portion for alkaline solution and aluminosilicate source for geopolymer were as follow:

Fly Ash	NaOH		Na_2SiO_3	Extra Water	
kg/m^3	kg/m^3	Mol	kg/m^3	kg/m^3	%
350	41	8	104	35	10

Table 4.2.1: Proportion of geopolymer in Density Parameter

Volume	Fly Ash	NaOH		Na_2SiO_3	Extra Water	
(m^3)	kg	kg	Mol	kg	kg	%
0.002	0.7	0.082	8	0.208	0.07	10

Table 4.2.2: Proportion of geopolymer in kg

Fly ash, sodium hydroxide, sodium silicate and water were mixed using mixer to make sure the compounds is well mixed.

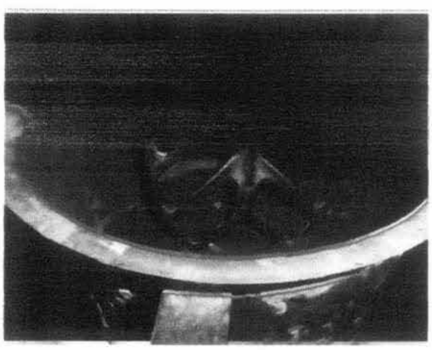


Figure 4.2.1: Mixing geopolymer

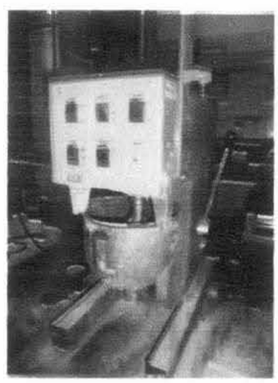


Figure 4.2.2: Mixer

After the mixing process, the geopolymer being poured into the porous asphalt while it placed on the operated vibrating table. This is to make sure the pores inside being filled with geopolymer. This process is done until there is no bubbles come out anymore. It indicates the void or pores is already being filled.

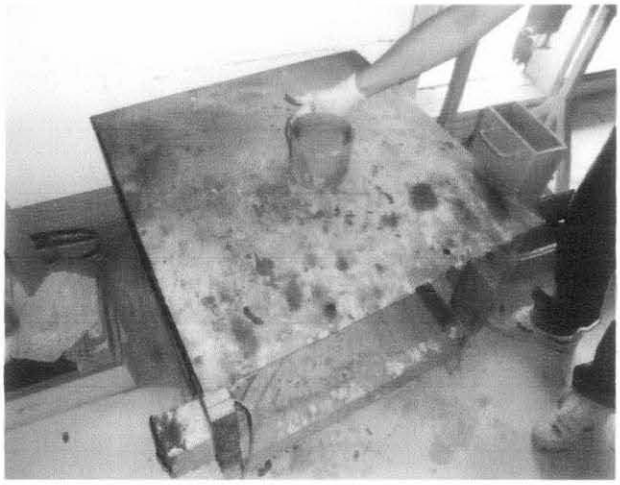


Figure 4.2.3: Sample on vibration table

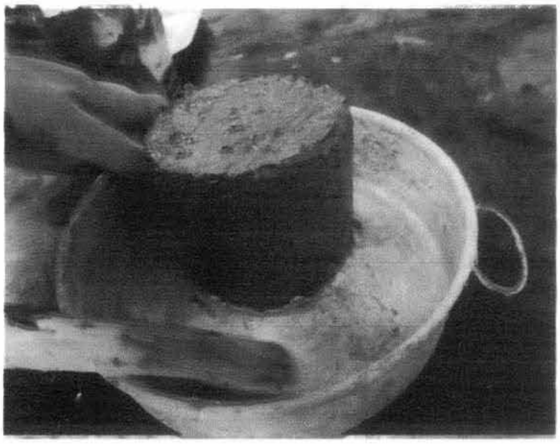


Figure 4.2.4: Finished sample

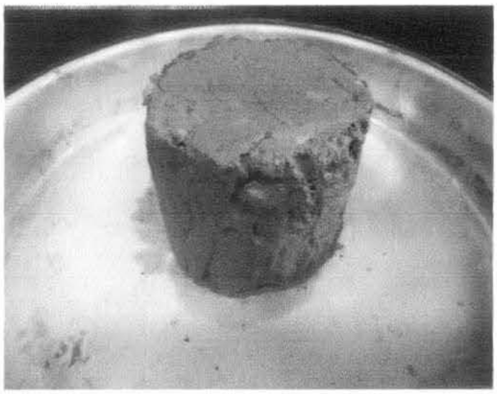


Figure 4.2.5: Hardened sample

After the curing process done (for7 days), the geopolymer are supposed to be fully hardened. Then only the laboratory test can take place.

4.3 PROBLEMS FACED

During the preparation of sample, we faced a few technical problems which make the project behind the schedule.

1. Low of number of blows.

   The compaction was not in good condition where the amount shown at the machine is not same with the manually count. The machine counter keep inconsistently such the number shown is 75 blows but when we count, it gives only about 50 to 60 blows. We figured this out after about a few samples have been done. The consequence of this, the samples was easily broken as it wasn't compacted well. Therefore, we need to do the manual count every time we want to compact the sample. It was a time wasted because there are other students also using this laboratory so we need to wait our turn to re do the sample.

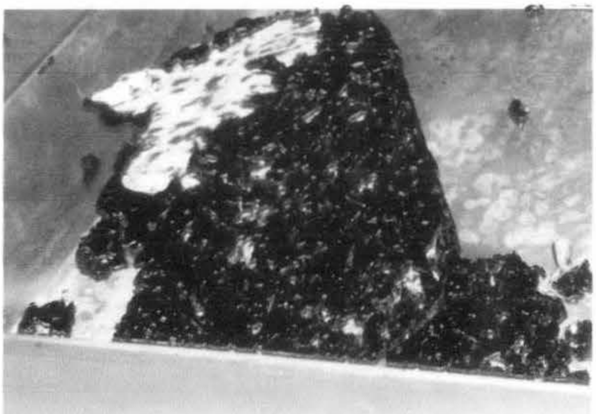


Figure 4.3.1: The broken sample

2. The fly ash used

   The second major problem is about the quality of fly ash that we used to make the geopolymer mix. The first fly ash we used is not a good one because it takes long time in order to be hardened. We can see the different color and textures below:

Figure 4.3.2: Low quality of fly ashes.

Figure 4.3.3: Higher quality fly ashes

4.4 LABORATORY TEST

The test that being chosen is Modified Lottman Test (AASHTO T283) as it was the most preferable test and the result gain is effective that proved from previous study. Modified Lottman test is applying 'Indirect Tensile Test' to determine the tensile strength of the samples. The tensile strength ratio of asphalt mixes is an indicator of their resistance to moisture susceptibility. The test was carried out according to AASHTO T283 specifications by loading a Marshall specimen with compressive load acting parallel to and along the vertical diametric-loading plane. Then we need to compare the strength of conditioned (saturated) and unconditioned (dry) samples to determine the Tensile Strength Ratio.

4.4.1 Conditioned Samples

The conditioned samples are representing the samples at field about 4 to 12 years. The test procedure is as follows:

1. The specimens are placed in a vacuum container supported a minimum of 1 in. (25 mm) above the container bottom

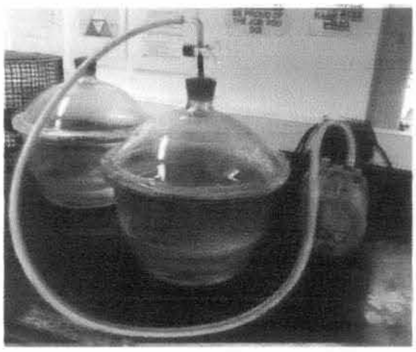


Figure 4.4.1: Saturation process

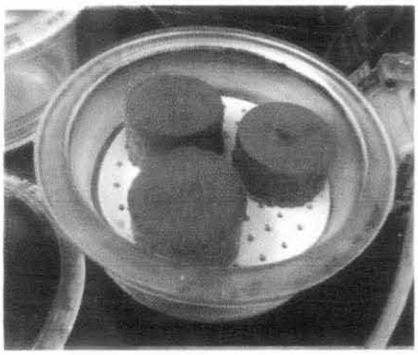


Figure 4.4.2: Samples in container

2. The container is filled with potable water at room temperature so that the specimens have at least 1 in. (25 mm) of water above their surface.
3. A vacuum of 10-26 in. Hg partial pressure (13-67 kPa absolute pressure) is applied for approximately 30 minutes.
4. The vacuum is removed and the specimen is left submerged in water for approximately10 minutes. The weight of the saturated, surface-dry specimen after partial vacuum saturation (B1) is determined by Method A of AASHTO T 166. The volume of absorbed water (J1) in cubic centimeters is determined by the following equation

   $J1 = B1 - A$

   where:

   J1 = volume of absorbed water, cubic centimeters

   B1 = weight of the saturated, surface-dry specimen after partial vacuum saturation, g

   A = weight of the dry specimen in air, g

4.4.2 Unconditioned Samples

At the end of the curing period, the dry subset is wrapped with plastic or aluminum foil in a heavy duty, and leak proof. The specimens are then placed in a 77 ± 1°F (25 ± 0.5°C) water bath for 2 hours ± 10 minutes with a minimum of 1 in. (25 mm) of water above their surface.

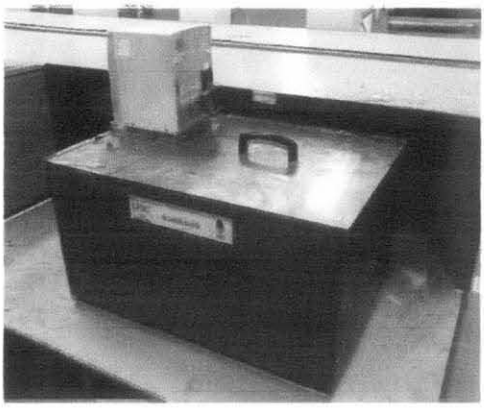


Figure 4.4.2: Water bath

4.4.3 Testing

The specimen is removed from the bath, the thickness determined, and then placed on its side between the bearing plates of the testing machine. Steel loading strips are placed between the specimen and the bearing plates. A load is applied to the specimen by forcing the bearing plates together at a constant rate of 2 in. (50 mm) per minute.

Figure 4.4.3a: Tensile Machine

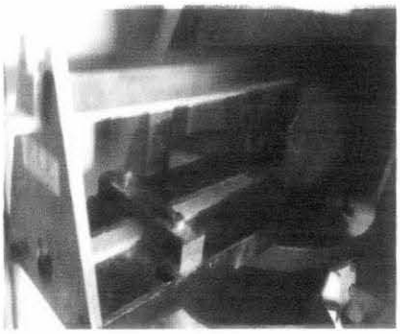
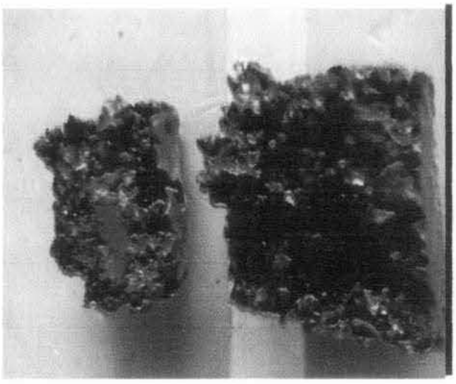


Figure 4.4.3b: Sample during tensile test

The maximum load is recorded, and the load continued until the specimen cracks. The machine is stopped and the specimen broken apart at the crack for observation.



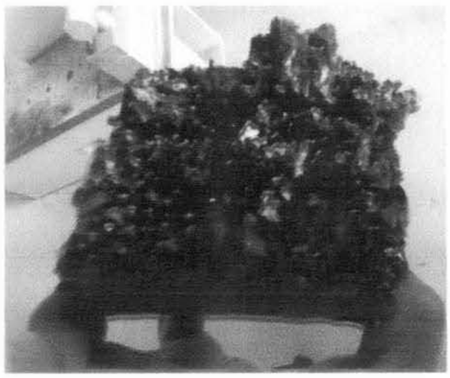


Figure 4.4.3c: Broken sample *Figure 4.4.4d: Observing the sample*

4.4.4 Calculations

The tensile strength is calculated using the following equation:

$$St = \frac{2000\,P}{\pi\, t\, D}$$

where:

St = tensile strength, kPa

P = maximum load, Newtons

t = specimen thickness, mm

D = specimen diameter, mm

The tensile strength ratio is calculated as follows:

Tensile Strength Ratio (TSR) = $\frac{S2}{S1}$

where:

S1 = average tensile strength of the dry subset, psi (kPa)

S2 = average tensile strength of the conditioned subset, psi (kPa)

CHAPTER 5

RESULT & DISCUSSION

5.1 DIAMETER & THICKNESS OF SAMPLES

SAMPLES	DIAMETER				THICKNESS			
	1	2	3	AVERAGE	1	2	3	AVERAGE
A	102.46	102.02	102.47	**102.32**	75.96	76.04	75.51	**75.84**
B	102.40	102.78	102.49	**102.56**	84.18	84.02	83.98	**84.06**
C	102.45	103.20	103.34	**103.00**	85.71	86.45	85.17	**85.78**
D	105.27	103.60	106.34	**105.07**	87.97	88.56	87.64	**88.06**
E	106.51	104.94	104.70	**105.38**	86.84	85.81	86.09	**86.25**
F	103.73	104.14	102.44	**103.44**	85.35	85.81	85.65	**85.60**

Table 5.1: Diameter & Thickness of samples

The Marshall sample should be 100 mm of diameter, but because of the coat from geopolymer, it become thicker in size.

5.2 PERCENTAGE OF AIR VOID

Sample	Weight Dry (g)	Weight Submerge (g)	Weight Surface Dry	Gmb	Percent Air Void (%)
1	1390	763.5	1384	2.240128928	8.606386748
2	1558	848.4	1568	2.165091718	11.66778278
3	1506	825.2	1515	2.183241519	10.92730042
				Average	**10.40048998**

Table 5.2: Percentage of Air Void

Air Void in Geopolymer Bituminous Mixture Calculations

- Va, Percent air void:

$$V_a = \left(1 - \frac{G_{mb}}{G_{mm}}\right) \times 100$$

- Gmb, Bulk specific gravity of the compacted mixture:

$$G_{mb} = \frac{W_D}{W_{SSD} - W_{sub}}$$

W_D is Dry weight

W_{SSD} is Saturated surface dry (SSD) weight

W_{SUB} is Weight submerged in water

- Gmm, Maximum theoretical specific gravity of the mixture :

$$G_{mm} = \frac{1}{\frac{1-P_b}{G_{se}} + \frac{P_b}{G_b}}$$

P_b, Asphalt content by weight of mix (percent) = 5%

G_{se}, Effective specific gravity of the aggregate = 2.643 (from previous study)

G_b, Asphalt binder specific gravity = 1.03 (from previous study)

So, we obtained G_{mm} = 2.45

The average percent of air void of geopolymer bituminous mixture is **10.4** which mean it still contain high percentage of voids that not being filled by geopolymer slurry. This is because of the slurry couldn't fully penetrate into the overall porous asphalt as the slurry's concentration is slightly high according to time. If we pour the slurry slowly, it will become thicker and hard to penetrate. This is one of the problem that we faced during the mixing process. The other factor may caused this problem is come from the interlocking of aggregate-binder is high due to the compaction.

5.3 DEGREE OF SATURATION

Volume air void:

	E, SAMPLE VOLUME (cm3)	Pa, AIR VOID (%)	Va, VOLUME AIR VOID (cm3)
A	623.5365032	10.4	64.84779633
B	694.3957605	10.4	72.21715909
C	714.6697268	10.4	74.32565159

Table 5.3a: Volume Air Void

$$Va = \frac{PaE}{100}$$

Sample Volume= $\frac{\pi D^2 T}{4}$

Volume water absorbed:

	WEIGHT DRY (g)	WEIGHT AFTER SATURATION (g)	J1, VOLUME ABSORBED WATER (cm3)
A	1348	1390	42
B	1493	1542	49
C	1540	1590	50

Table 5.3b: Volume Absorbed Water

J1= Saturated Weight – Dry Weight

Degree of Saturation:

	S1, DEGREE OF SATURATION
A	64.7670428
B	67.85091053
C	67.27152595
AVERAGE	66.62982643

Table 5.3c: Degree of Saturation

$$S_1 = \frac{100\, J_1}{Va}$$

The degree of saturation for 40 minutes is lower than 30%, so we need to add more time so that the degree could achieve. For this, we continued the saturation process same for concrete cylinder that is about 4 hours because the water hardly saturated through the hardened geopolymer. Besides, the geopolymer coat is almost solid as concrete.

5.4 MAXIMUM LOAD & TENSILE STRENGTH OF SAMPLES

	Sample	Diameter (mm)	Thickness (mm)	Maximum load (N)	Tensile Strength(kPa)	AVERAGE TENSILE STRENGTH (kPa)
CONDITIONED	A	102.32	75.84	24100.00	1977.30	**1618.48**
	B	102.56	84.06	17800.00	1314.46	
	C	103.00	85.78	21700.00	1563.68	
UNCONDITIONED	D	105.07	88.06	37300.00	2566.54	**2218.02**
	E	105.38	86.25	29000.00	2031.25	
	F	103.44	85.60	28600.00	2056.27	

Table 5.4: Tensile Strength

Where:

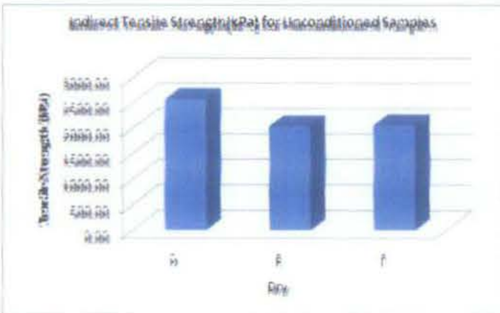
$$St = \frac{2000P}{\pi\, t\, D}$$

Therefore:

$$TSR = \frac{S2\ (\text{Avg Conditioned})}{S1(\text{Avg Unconditioned})} = \mathbf{\underline{0.73}}$$

5.5 CHARTS

The charts below are to summarize the tensile strength for dry and saturated condition.



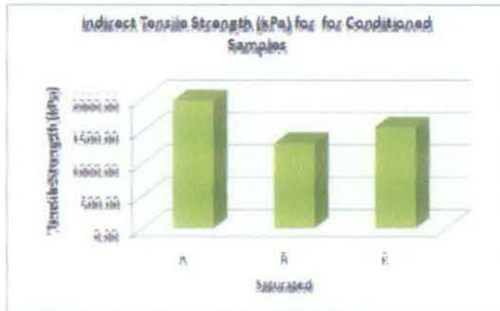


Figure 5.5a: ITS Unconditioned. *Figure 5.5b: ITS Conditioned*

The inconsistent of value resulted because the different samples give the differences in term of size and structure. Therefore, this test takes the average of 3 samples each batch.

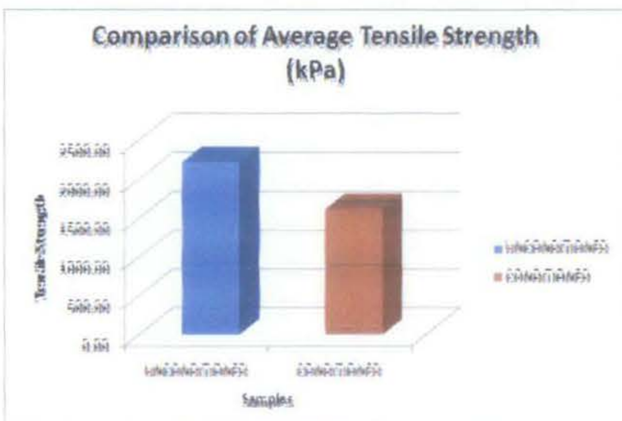


Figure 5.5c: Tensile Strength Comparison

The chart above showed the comparison between both average of unconditioned and conditioned tensile strength. This is the normal result for every test where the dry sample will give higher value as it contains no moisture. It can achieve the maximum tensile strength of 2218 kPa. The conditioned sample is the one that representing a pavement that having moisture susceptibility situation on field for about 4-12 years.

5.6 DISCUSSION

According to Robert P. Lottman in his research on Predicting Moisture-Induced Damage to asphaltic Concrete (NCHRP report 192), the average of the laboratory tests on normal pavement gives the average Tensile Strength 732 kPa for dry and 593 kPa for saturated specimens.

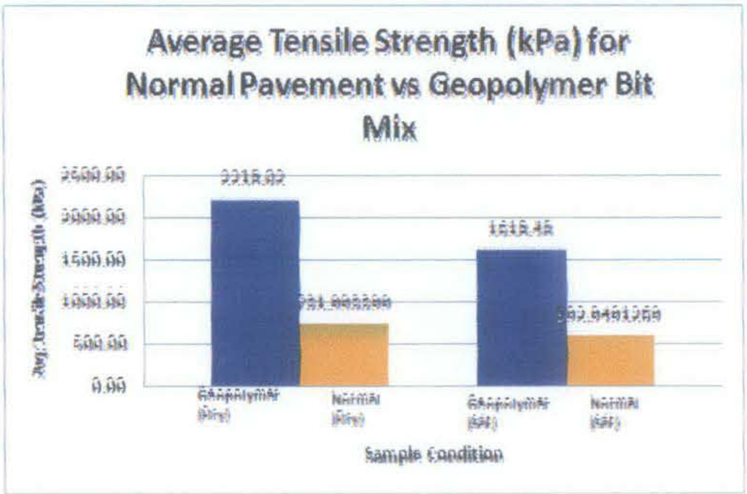


Figure 5.6: Geopolymer vs Norma

This is a big difference with geopolymer bituminous mixture where from the test, whereby it resulted 2218.02 kPa for dry meanwhile 1618.48 kPa for saturated. From the result, we can see geopolymer mix can withstand the load about 2 times than normal pavement's tensile strength. We can see that although the geopolymer is being conditioned, it still have higher value than dry normal pavement.

Tensile Strength Ratios represent the fraction of the dry mechanical property that has been retained after application of vacuum saturation. The normal pavement from above experiment gives about 0.81 of TSR's average. For geopolymer mix, the TSR is 0.73 which are within the acceptable value that is 0.7 to 0.8. This indicates the mix doesn't give large strength decrease. Therefore we can conclude the geopolymer mix can caused further reduction of tensile strength which is also reducing the effect of moisture susceptibility damages.

CHAPTER 6

CONCLUSSION & RECOMMENDATION

6.1 CONCLUSION

By conducting this project, we can achieve the main objective which is to determine one of the performance characteristic of geopolymer bituminous mixture that is moisture susceptibility. This will assure which mixture is more effective toward resisting stripping and also relevance to be used on field.

From the result gained, it shows that the usage of geopolymer inside bituminous mixture could reinforce and increase the strength of pavement. The moisture susceptibility inside geopolymer bituminous mixture can be reduced as the strength is increased. Hence, it could give a positive impact on the economic perspective as the maintenance cost getting lower.

Besides, geopolymer bituminous mixture can be consider as environment friendly because the product of geopolymer is reusing waste product such as fly ash as the aluminosilicate source. According to Duxson (2007), the reactivity of the fly ash glasses is used to generate a binder comparable to a hydrated Portland Cement in appearance and properties, but with possibly reduced CO_2 emissions.

It should be noted that when the total carbon footprint of the alkali required forming geopolymer cement is considered, including the calcining of limestone as an intermediate to the formation of alkali, the net reduction in total CO_2 emissions may be negligible. Moreover, handling of alkali can be problematic and setting of geopolymer cements is very rapid (minutes versus hours) as compared to Portland cements, making widespread use of geopolymer cements impractical at the ready mix level. So, it can replace the usage of Ordinary Portland Cement on asphaltic concrete pavement construction that emits high Carbon Dioxide (CO2) gasses to surroundings.

6.2 RECOMMENDATION

The finding of geopolymer in bituminous mixture is still new and fresh in the highway construction. The properties and performance will need to be exposed more. Therefore, in order to get more understanding of the research on this topic, there are some improvisations can be done by further researcher.

We can varies the components inside the mixture such as the porosity of porous asphalt, grade of bitumen, types of fly ash, different percentage of water and more. In other hand, we also can study on the different method of testing to get the moisture susceptibility such as Immersion-Compression Test, Tunnicliff and Root Conditioning Test, and also applying freeze and thawn process inside Modified Lottman Test.

Besides, there also other research can be done on the curing process of geopolymer bituminous mixture, fabrication of porous asphalt using 60/70 bitumen, and also study on the period to pour the geopolymer slurry. We need to understand those things because from this project, we found some difficulties such as uncertainty of curing process. The curing process need to apply because the geopolymer's coat shows some crack after hardened. Other than that, we also can do some study on when to pour the geopolymer such as during mixing, after compaction or after removing the porous asphalt from it mould.

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