PERFORMANCE OF POROUS ASPHALT INCORPORATING CELLULOSE FIBER

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Thesis submitted in fulfillment of the requirements
for the award of the
Bachelor Degree in Civil Engineering

Faculty of Civil Engineering and Earth Resources
UNIVERSITI MALAYSIA PAHANG

MAY 2019

ACKNOWLEDGEMENTS

Foremost, I would like to thank Allah S.W.T for His blessing and help. With His Strength and mercy, I have successfully completed this research study and my degree on time. I also would like to thanks to everybody who contributed in this project from early moment until the end of my degree here.

Foremost, I am very thankful and appreciate to my supervisor, Dr. Khairil Azman Bin Masri for full guidance and knowledge sharing throughout my research study. I also owe his dedication and patience in time to complete my degree's project.

Not forgotten, to all technician and staff of UMP's Highway and Transportation Laboratory, En Mohd Sani, Pn Siti Sarah and En Amir Asyraf for their commitments and guidance during my laboratory test. With the quality serves, I have successfully completed all laboratory tests.

Last but not least, I am very thankful to my parents and sisters for their encouragement and always be on my side during my study in Universiti Malaysia Pahang. Without them, I will never complete my degree in Civil Engineering.

ABSTRAK

Asphalt berliang (PA) mempunyai struktur lapisan terbuka berbanding campuran asfalt padat. Oleh itu, PA boleh meningkat keselamatan semasa hujan kerana air struktur terbukanya. Tetapi, PA mempunyai kelemahan dari segi kestabilan dan ketahanan kerana jumlah besar lompang udara. Oleh itu, dalam kajian ini, selulosa Fiber (CF) akan bercampur dengan pengikat untuk memperbaiki sifat-sifat PA dan jenis CF digunakan adalah dalam jenis pelet. CF dikenali sebagai agen penstabil yang mempunyai kandungan asfalt yang lebih tinggi, lapisan filem tebal dan kestabilan campuran yang lebih tinggi. Oleh itu, CF mempunyai keupayaan untuk meningkatkan kekuatan PA. Kajian ini memberi tumpuan kepada kewujudan CF dalam mengikuti perintah 0% (sebagai sampel tidak diubahsuai), 0.2%, 0.3%, 0.4%, 0.5% dan 0.6% .Tujuan kajian ini adalah untuk mengkaji kesan CF pada sifat kejuruteraan PA penggredan B. Antara ujian makmal yang terlibat untuk menilai prestasi CF-PA adalah lelasan, Marshall Kestabilan, Resilient Modulus dan Dinamik Creep. Ujian lelasan untuk menilai permukaan kekuatan CF dan PA mengikat bersama-sama dengan bitumen dan hasilnya menunjukkan kekuatan permukaan yang lebih tinggi pada penambahan 0.4% CF. Untuk ujian kestabilan, ia dinilai beban maksimum boleh digunakan untuk PA sebelum kegagalan berlaku dan ia dipengaruhi oleh ketumpatan PA. Oleh itu, hasil ujian menunjukkan pada nilai yang lebih tinggi kestabilan dan ketumpatan pada penambahan 0.6% CF. Selain itu, ujian modulus yang berdaya tahan menentukan bagaimana CF dipengaruhi oleh beban trafik dan keadaan suhu. Oleh itu, hasilnya pada 0.6% CF nilai yang lebih tinggi modulus berdaya tahan pada loading lalu lintas dan keadaan suhu. Akhir sekali, ujian prestasi bagi rayapan dinamik untuk menentukan rintangan campuran asfalt untuk aluran di 25˚C dan sampel yang terbaik pada 0.2% CF. Oleh itu, kewujudan CF mampu meningkatkan prestasi PA. Untuk kajian masa depan, ia mencadangkan untuk menganalisis kelakuan mekanikal dan mikrostruktur PA dengan kewujudan CF dalam jenis bentuk yang longgar untuk dikenali mereka stabil di PA.

ABSTRACT

Porous Asphalt (PA) has an open structure layer compared to dense asphalt mixture. Thus, PA can increased the safety during rainfall due to its open structure water. But, PA have weakness in terms of stability and durability due to large amount of air voids. Therefore, in this study, Cellulose Fiber (CF) were mix with the binder to improve the properties of PA and the type of CF used was in pellets type. CF known as a stabilizing agent that have higher asphalt content, thick film coating and higher mix stability. Thus, CF has ability to improve the strength of PA. This study focuses on the existence of CF in following order 0% (as a unmodified sample), 0.2%, 0.3%, 0.4%, 0.5% and 0.6%.The aim for this study is to investigate the effect of CF on engineering properties of PA grading B. The laboratory test involved to evaluate the performance of CF-PA were Abrasion, Marshall Stability, Resilient Modulus and Dynamic Creep. The Abrasion test to evaluate surface strength CF and PA bind together with asphalt binder and the result shows that higher surface strength at the addition of 0.4% CF. For the stability test, it to evaluated the maximum load can applied to PA before failure happened and it influenced by the density of PA. Therefore, the result of testing shows at higher value of stability and density at addition of 0.6% CF. Moreover, the resilient modulus test determine how CF influenced by traffic loading and temperature condition. Thus, the result at 0.6% CF the higher value of resilient modulus at traffic loading and temperature condition. Lastly, the performance test for dynamic creep to determine the resistance of asphalt mixture to rutting at 25˚C and the best sample at 0.2% CF. Thus, the existence of CF is capable enhancing the performance of PA. For the future study, it is recommend to analyze the mechanical behavior and microstructural of PA with existence of CF in type of loose form in order to known their stabilizing in PA.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

HMA	Hot Mix Asphalt
DGA	Dense Graded Asphalt
SMA	Stone Mastic Asphalt
PA	Porous Asphalt
CF	Cellulose Fiber
SF	Steel Fiber
GF	Glass Fiber
SP	Synthetic Fiber
JKR	Jabatan Kerja Raya
DBC	Design Binder Content
LA	Los Angeles
BST	Bituminous Surface Treatment
PMA	Polymer Modified Asphalt
FKASA	Fakulti Kejuruteraan Awam & Sumber Alam
UMP	Universiti Malaysia Pahang
ASTM	American Society for Testing & Material
UTM	Universal Testing MAchine

CHAPTER 1

INTRODUCTION

1.1 Introduction

Hot mix asphalt (HMA) or asphaltic concrete are the commonly used in Malaysia for design the roads. HMA consists of two basic ingredients which as aggregate and asphalt binder or bitumen. The process of HMA is to determine the gradation aggregate, optimum asphalt binder and the optimum combination of aggregate and asphalt binder ought to be. The minerals aggregate consists of coarse and fine particles as the structural skeleton of the pavement. The bitumen normally used in construction road and highways to bind together the graded minerals (Al-Hdabi, 2016). The aggregate and asphalt binder are highly sensitivity to manage compared with other materials used in construction pavement (Abtahi et al., 2009).

The type of pavement is flexible pavements and rigid pavements and in Malaysia, flexible pavement commonly used in road construction. There are three layers of flexible pavement which is surface course, base course and sub-base course. In surface course are divide into three type of surface. It is Dense Graded Asphalt (DGA), Stone Mastic Asphalt (SMA), and Porous Asphalt (PA). PA is a type of mixture that consists of relative coarse aggregate that bound together with a sand, filler, and bitumen. PA is construct to improve the pavement of skid resistance during raining, reduce splashing effect and produce lower rising noise (Liu Q & Cao. D, 2009). This is because the interconnected voids allow the rainwater to be store and move horizontally in the PA mixture.

Nowadays, there are many research or study trying added new additives either into the asphalt binder or in the asphalt mixture to improve the properties of asphalt mixtures such as their stability and durability (H. Chen & Q. Xu, 2010). Therefore, with adding the fibers into the asphalt binder or asphalt mixtures to ensures the stability and mechanical strength of asphalt mixtures (R. Xiong et al., 2015). There are many types of fiber has been used in asphalt mixture such as Cellulose Fiber (CF), Steel Fiber (SF), Glass Fiber (GF), Synthetic Polymer (SP) and Recycle Tire Fiber (M. Manosalvas et al., 2016). The common type of fiber used as a additive in asphalt mixtures is CF. The benefits of CF as the stabilizing agent are had higher asphalt content, thick film coating and higher mix stability.

M. Mohammed et al., (2018) claims that due to the correct of quantity fiber used in the asphalt mixtures, the asphalt mixtures properties would change such as reduces the penetration, increase the softening point and at the same time, the bitumen of viscoelasticity also change. Besides that, the existence of fiber into the asphalt mixture shows that increasing the dynamic modulus of asphalt mixtures, reducing the thermal susceptibility. Thus, it can enhance the material strength, ductility and fatigue behaviour. Moreover, there are several research claims that addition of fiber into asphalt mixtures in PA reduce the drain down problems (V.C. Andres-Valeri et al., 2018)

1.2 Problem Statement

As known, Malaysia is one country that heading towards infrastructure development and Malaysia is having two condition which are having higher temperature and having heavy rainfall throughout the year. Thus, it leads the risks towards the progressive waterproofing of soil and reduce the area for water infiltration. The hydrologic factors will affects by increasing the surface runoff. In PA mixtures, the water that penetrate sometimes remains in the structure and indirectly it kept the asphalt mixtures in wet condition for a long time. Therefore, the mixture moisture can cause a damage in PA by stripping the asphalt binder from the aggregate surface. Besides that, the asphalt concrete also facing a lot of division such as rutting and stripping. The damages in asphalt pavement such as rutting occurred when a temperature changed (Kandhal Prithvi S. & Allen Cooley Jr L., 2008). Indeed, rutting can affect operation of safety when it reaches critical depths (Ali, 2006). The rainfall will leads to the accident and traffic congestion due to the water ponding above the pavement. Thus, it cause the skidding and splashing. Besides that, they are expose to heavy traffic loading and will effect the performance asphalt mixture in terms of its resilient modulus and rutting resistance.

Yusoff et al., (2014) explored due to increase to traffic volume use of heavier axle load, new axle configuration and higher tire pressure, the demand on highway pavement and asphalt layers have increased, required to enhance the performance of asphaltic materials. Therefore, the method to overcome this problem is modifying the asphalt binder properties. Since fiber composite tends to provide improvement of properties for materials, these studies intended to promote Cellulose Fiber (CF) as asphalt binder modified in order to enhance the properties of asphalt mixture.

1.3 Objective

The aim of this study is to enhance the properties of Porous Asphalt in terms of Abrasion, Stability, Resilient Modulus and Dynamic Creep with the existent of Cellulose Fiber. The objectives for this study are:

1) To evaluate the mechanical performance of Porous Asphalt incorporating Cellulose Fiber.

2) To determine the Optimum Fiber Content of Porous Asphalt.

1.4 Scope of Research

This study focus on using Cellulose Fiber as modified of bitumen in Porous Asphalt. The gradation used for this study is Porous Asphalt Grading B as stated in JKR Specification for Road Works (JKR/SPJ/2008). Besides that, the binder used was Penetration Grade 60/70 and JKR Standard Specification for Road Works was referred as guideline for design binder content (DBC). The aggregate obtained from Highway &Traffic Laboratory University Malaysia Pahang. The additive used was Cellulose Fiber with increment 0%, 0.2%, 0.3%, 0.4%, 0.5%, and 0.6%.

The test conducted to determine the Abrasion was Los Angeles (LA) Abrasion Test with two sample at every each percent of Cellulose Fiber. Besides that, The Marshall Stability Test was carry out for two sample each for control and modified Porous Asphalt sample. Furthermore, Resilient Modulus Test was carry out with repeated load on one sample for each percentage of Cellulose Fiber at 1000ms, 2000ms, and 3000ms while Dynamic Creep Test was carried out for one sample each for control and modified Porous Asphalt.

1.5 Significance of Research

This study is focus to investigate the best percentage of Cellulose Fiber (CF) used as an additive material in Porous Asphalt grading B. CF are the fibers that made from ethers or esters of cellulose where can be obtain from the wood or leaves of plants. Besides that, CF also can obtained from recycled newspaper. Thus, using CF in pavement construction is better for environmental safe and environmental friendly compared to other type of fibers.

Besides that, CF can give better impact to the other materials such as in terms of durability and stability of PA (H. Chen and Q. Xu, 2010). At any temperature seasons, CF makes asphalt film more stable. It is because, when high temperature, the asphalt were expand and the CF will be a buffer room. Indirectly, CF can prevent free bleeding asphalt while CF will be prevent cracking during cold temperature. Chen et al., (2008) claim that the existing of CF in asphalt mixture reduce the sensitivity of binder at any temperature present. Thus, it improve the performance of PA against at high and cold temperature damage. Moreover, CF are wide availability to found and have lower costing. Thus, it can reduce the cost of construction because can reduce the use of natural resources and provide lower cost pavement's maintenance because of service life increased.

CHAPTER 2

LITERATURE REVIEW

2.1 History of Pavement

The history of pavement is start in the Romans era, then move to the Macadam and Telford era, and lastly move to the asphalt and concrete Portland cement concrete pavement. This chancing give view that how the design, construction, and performance of pavement has evolved and help to give perspective on present and future practice. In Roman era, Roman roads did not use asphalt as a binder, but they always use lime gout and natural pozzolans as a binder. Figure 2.11 shows the road structure in Roman.

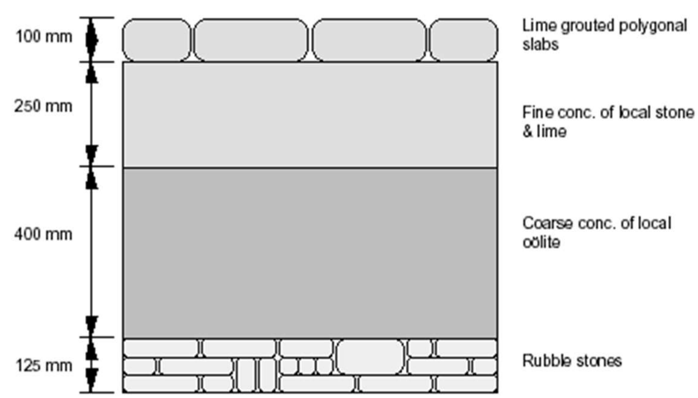


Figure 2.1 Road Structure in Roman

After a several thousand years, Telford pavement start begin to show the similarity with the modern HMA pavements. Thomas Telford had joined served as apprentice as mason building. From that, he expand his knowledge in masonry for bridge building. After Telford become the Surveyor of Public Works, he turns his attention to the road design. He tries to build roads with using flat grades that have slope not more than 30 in order to reduce the number of horses needed to haul cargo. The depth of Telford's pavement was about 14 to 18 inches as shown in Figure 2.2, and it did not use any binding to hold the stones together.

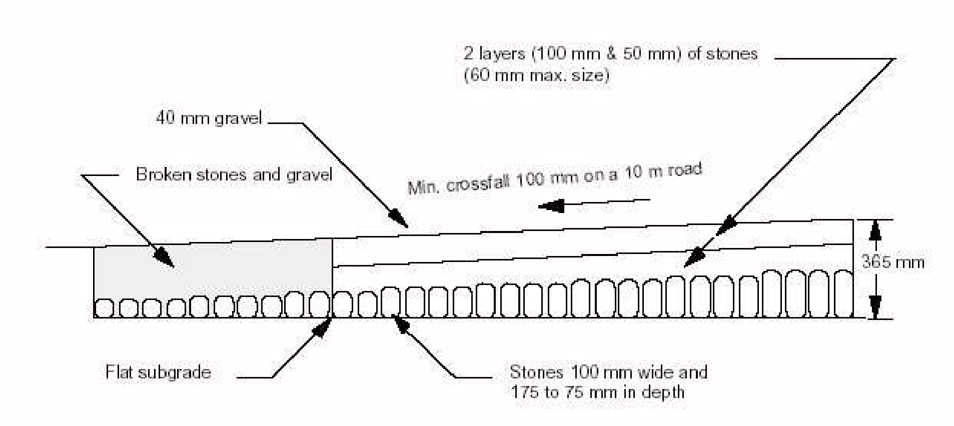


Figure 2.2 Telford Road

Macadam pavement was from John McAdam introduced use the angular aggregates. He believes this type of aggregates when well-compacted subgrade would perform better. Besides that, he also used the sloped concept for subgrade surface to improve the drainage where is the angular aggregate in two layer for a total depth was 8 inches. On top of the pavement, the thick of wearing course about 2 inches with a maximum aggregates size was 1 inch. Macadam realized that the layers of broken stone would bound together with fines generate by traffic if it did not use any bind medium to hold the stones together. Figure 2.3 show the road structure for Macadam road.

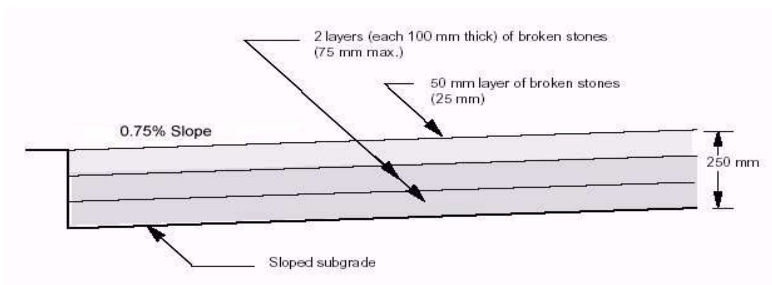


Figure 2.3 Macadam road

2.2 Type of Pavement

There are two types of pavements are flexible and rigid pavement, and the difference is based on the manner in which the loads are distributed to the subgrade.

2.2.1 Flexible Pavement

The flexible pavement are the surfaced coating with bitumen and asphalt materials. This type pavement called flexible because the pavement structure will deflect or flexes when under loading. Typically, these pavement structures has composed of several layers of materials, and it shows at Figure 2.4. At every each layers will receive the loads from the above layer and spreads the loads out, then passes them to the next layer below. Thus, the layer at the bottom in the structure pavement is had the less load to carry. Flexible pavement can be either in the form of pavement surface treatment such as Bituminous Surface Treatment (BST) or HMA surface courses. Bitumen is a component of asphalt binder that combines course aggregate, fine aggregate and mineral powder in the monolith (Kishchynskyi et al., 2016).

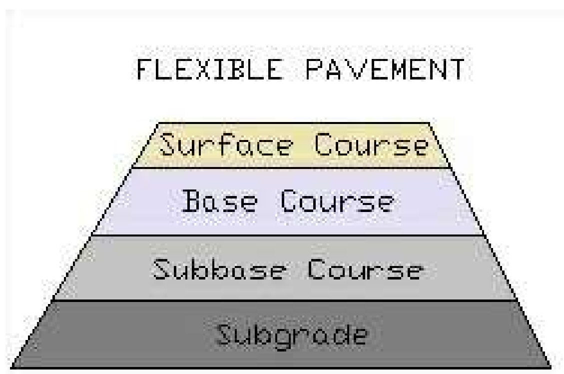


Figure 2.4 Layer of flexible pavement

The BTS is helps to prevent the penetration of surface water to the base course. Thus, it give a smooth and well-bounded surface that are free from loose particles. Therefore, if the water can penetrate into the base course, it can be a danger to road users. Gopal Mishra, (2011) claim that the BTS also can resists the stress by vehicle loads as well as increase the skid resistance surface. Moreover, the base course were transfer the loading by vehicle to the subgrade and subbase. Thus, to withstand the stress, the thickness and materials use in base course need to design correctly to avoid the failure in the subbase or subgrade. The durable aggregates can be into two categorized which are stabilized and granular.

2.2.2 Rigid Pavement

The rigid pavement is construct from cement concrete or reinforced concrete slab. To construct this type of pavement by provide a cement concrete slab of sufficient strength to resist the loads from traffic. Thus, it increase the modulus of elasticity and rigidity due to distribute the load over wide area of soil. For this design, the strength of subgrade have little influence on the structural, but the flexural strength of concrete have more influence in rigid pavement. The figure 2.5 shows the layer of rigid pavement.

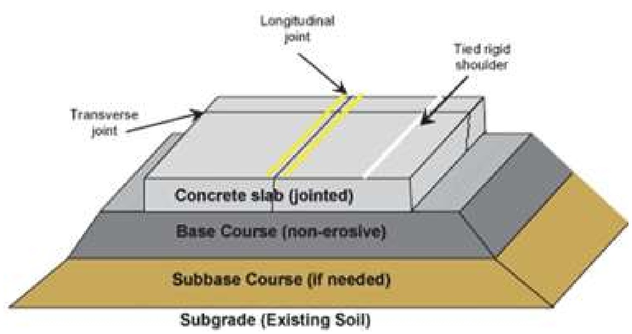


Figure 2.5 Layer of rigid pavement

2.3 Type of Flexible Pavement

In flexible pavement, there are many type of HMA pavements such as Dense Graded Asphalt (DGA), Porous Asphalt (PA), Stone Mastic Asphalt (SMA) and Polymer Modified Asphalt (PMA). All the type of HMA mix have different maximum aggregate size, aggregate gradation and asphalt binder content or type.

2.3.1 Dense Graded Pavement

A dense graded asphalt is a well-graded asphalt. This HMA provides the great impermeable characteristics of allow the water to run away from the surface area. The dense graded asphalt generally refer by their maximum aggregates sizes either fine-graded or coarse graded. Thus, it’s deriving their strength and stability through aggregate interlock. It can be proof with the previous studies that the properties of asphalt mixtures can be influenced by the inter particle friction and interlocking of aggregates. This type of asphalt is ideal for all traffic condition besides has great performance under structural condition, and friction. Figure 2.6 shows the structure of dense graded asphalt pavement.

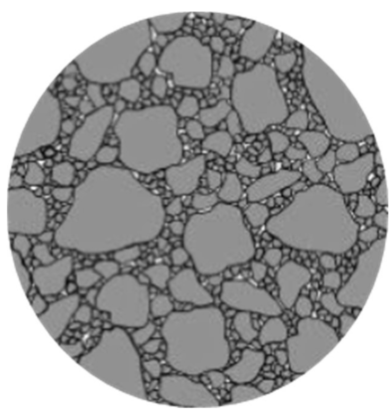


Figure 2.6 Dense graded Asphalt

2.3.2 Porous Asphalt

The porous asphalt (PA) or know as an open-graded asphalt has been used a wearing surface. This asphalt is develop for allowing the water enter into the asphalt mixes beyond its continuous air voids. After laying and compacting of PA, the surface area will form an air voids more than 20%. Thus, the PA can improve the skid resistance of pavement during rain, reducing the splashing effect and produce lower riding noise (Liu Q. & Cao D., 2009). The differences PA with dense graded is in PA the surface water can drain due to the large amount of pores in the structure but if the pores and clogging, it can reduce the functionality prematurely (Poulikakos D.L.et., 2006). Figure 2.7 shows the structure of porous asphalt pavement.

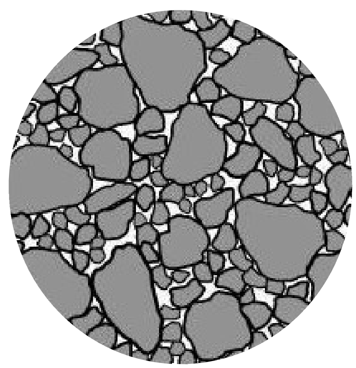


Figure 2.7 Porous Asphalt Pavement

2.3.3 Polymer Modified Asphalt

The polymer that filled or added with bitumen is to alter its unique conduct. First, to make the asphalt mixer better resistance towards rainfall and water stagnation. Besides that, the binding between bitumen and polymer increases and better bonding of the mix. Using this type of Polymer modified asphalt, the maintenance cost of road is almost nil. But when using some type of polymer can give disadvantages to asphalt such as the Toxics present in the plastic waste would start leaching (Rokade S., 2012).

2.3.4 Stone Mastic Asphalt

The Stone Mastic Asphalt (SMA) is a gap-graded HMA that originally started from Europe. It is develop to maximize the rutting resistance and durability. Since the aggregates do not deform like the asphalt binder under load, the stones contact greatly to reduce rutting. Van de Ven, at al., (Undated) also claim that the stones contact of an aggregate skeleton should be prevented the mix from become temperature sensitive and susceptible to permanent deformation at high temperature. But, the cost of SMA will increase if the binder and filler higher. So, the filler was higher in SMA would make the productivity of SMA reduced. Figure 2.8 shows the structure of Stone Mastic asphalt pavement.

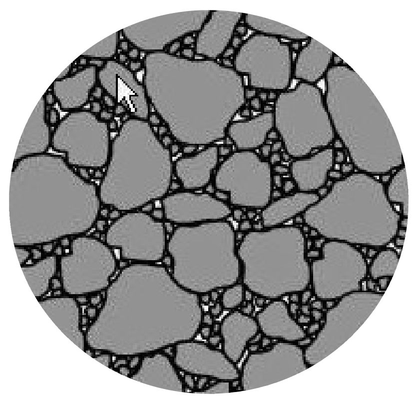


Figure 2.8 Stone Mastic asphalt pavement

2.4 Overview of Porous Asphalt

As is known, the design of Porous Asphalt (PA) need to refer their nominal maximum aggregate size. PA has two type of gradation which Porous Asphalt grading A and Porous Asphalt grading B. The nominal maximum aggregate size for PA grading A was 10mm while PA grading B was 14mm. Thus, the PA grading B have better strength of aggregate surface compare to PA grading A. The gradation of PA are evaluate by using JKR Specification Standard. The advantage using PA in the pavement can reduce the splashing and spraying in the pavement. It is because the surface of PA pavement can absorb the rainwater due to the large amount of continuous pores in the structure. Thus, it will provides a good visibility under the rainy conditions and prevent the reduction of traffic flow volumes during raining day.

Table 2.1 Gradation of aggregate according JKR Specification Standard

BS Sieve Size (mm)	**Percentage Passing by Weight**	
	PA grading A	**PA 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

2.4.1 Advantages of Porous Asphalt

There are several advantages of Porous Asphalt. Firstly, reduction in splashing, spray and aquaplaning (Liu Q & Cao D., 2009). Due to the large amount of pores in the PA, the surface water can drain through the asphalt mixtures. Thus, the absorption of surface water can reduce the aquaplaning occurs when the vehicles move at high speed on a thin water layer. Besides that, the surface of road for PA pavement are laid with different course size and when the tire and surface are contact, it contribute to the noise absorption between them. It is because, the increasing air voids content in PA tends to helps the noise reduction (M. Liu et al., 2016). Moreover, one of the main reasons using PA is to increase the skid resistance (Liu Q & Cao D., 2009).

2.4.2 Disadvantages of Porous Asphalt

PA have some disadvantages such as aging and stripping. The asphalt binder film continuously exposed to sunlight, water and other else. Thus, it make the binder hardening and indirectly, the pavement of service life become reduce. It because, when the asphalt binder hardens, the aggregates can stripped easily from the asphalt mixes. As well known, in the PA the rainwater can penetrate through the asphalt mixture and then the water can remains in the structure to keep the moisture of asphalt in wet condition. Thus, it moisture can cause the damage in PA by stripping the asphalt binder film from aggregate surface (Caglar Yalcinkaya, Undated). Moreover, the pores in PA mixtures tend to be clogged such as dust, dirt and other clogging agents. Thus, due to clogging the PA need periodic maintenance (Y. Zhang et al., 2016). Therefore, the service life of PA is shorter compared with DGA.

2.5 Overview of Fiber

Fiber is a natural or synthetic material that is used in the manufacture of material such as textile or paper and impregnated in materials for example cement and asphalt mixtures. Fiber are classified according to their origin as an organic or mineral fiber. The type of organic fiber was cellulose and lignite that commonly used in the manufacture of paper and textiles while mineral fiber include asbestos that refer to a group of silicate minerals. In construction pavement, H. Chen and Q. Xu (2010) claims that engineers are trying to improve the properties of asphalt mixttures in term of stability and durability by incorporated with fibers in the bitumen or in the asphalt mixtures. From the previous research, adding the fiber into the binder or asphalt mixture give better impact in their stability and mechanical strength (M. Muhammad, et al., 2018).

2.6 Cellulose Fiber

The Cellulose Fiber (CF) are one of the natural fiber commonly used as an additive materials in the asphalt mixtures. CF are the fibers that made from ethers or esters of cellulose where can be obtain from the wood or leaves of plants. The application of CF are in the textile industry as a chemical filters and fiber reinforcement composite. This is because the CF have similar properties to engineered fiber. The advantage of existence CF in pavement are can stop the binder drainage and prevent it is to loss during storage and transport (F. Martinho et al., 2013). CF are wide availability to get and have low relative cost.

2.7 Resilient Modulus

Resilient modulus is the ability of asphalt mixture to spread the loads and to control the level of traffic loading. Ibrahim (2005) claims that the asphalt mixture behaves elastically and plastically if the load is applied. Therefore, the traffic creates a tensile strain under of the asphalt mixture layers where subjected to cracking while the compression strain in the subgrade can lead to the permanent deformation. Thus, this test is helps to measure the elasticity of the asphalt mixtures. Besides that, this test also represent the condition of asphalt mixture that subjected to traffic load and ability of comparing the behaviour of asphalt mixture under various condition (Pourtahmasb et al. 2015).

2.8 Dynamic Creep

Dynamic creep test is to evaluate the resistance of PA towards permanent deformation. As well know, initially the permanent deformation occurs due to densification of asphalt binder layers and after that, due to plastic shear strains from asphalt binder layers. Therefore, it cause the displacement in the material of asphalt binder layer. Hafeez Imran (2011) claims that the repeated load deformation test are more useful comparing the rutting susceptibility. Thus, Universal Testing Machine (UTM) were used for this study and the strain test were applied from the cyclic duration and magnitude to specimens. In previous study, the existence of fiber in PA increase the dynamic modulus and enhance the material strength, fatigue behaviour and ductility.

Figure 2.9 Universal Testing Machine

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter discusses the procedure and methodology in conducting the test in order to achieve the objectives for this study. The methodology starts with the preparation and testing materials, then laboratory tests on aggregate. The test involved were Sieve & Analysis Test, Los Angeles (LA) Abrasion Test, Aggregate Impact Value Test, Aggregate Crushing Value Test and Flakiness & Elongation Test. Besides that, the test of binder which were the Softening Point Test, Standard Penetration Test and Ductility Test. The performance tests were the Los Angeles (LA) Abrasion Test, Marshall Stability & Flow Test, Resilient Modulus Test and Dynamic Creep Test. All the test and sample preparation were conduct in the Highway & Traffic Laboratory, FKASA UMP.

3.2 Flow Chart

Figures 3.1 show the methodology that were used for this study. The research starts from collecting all related information regarding the performance of Porous Asphalt with Cellulose Fiber as modified binder until the result & analysis of data.

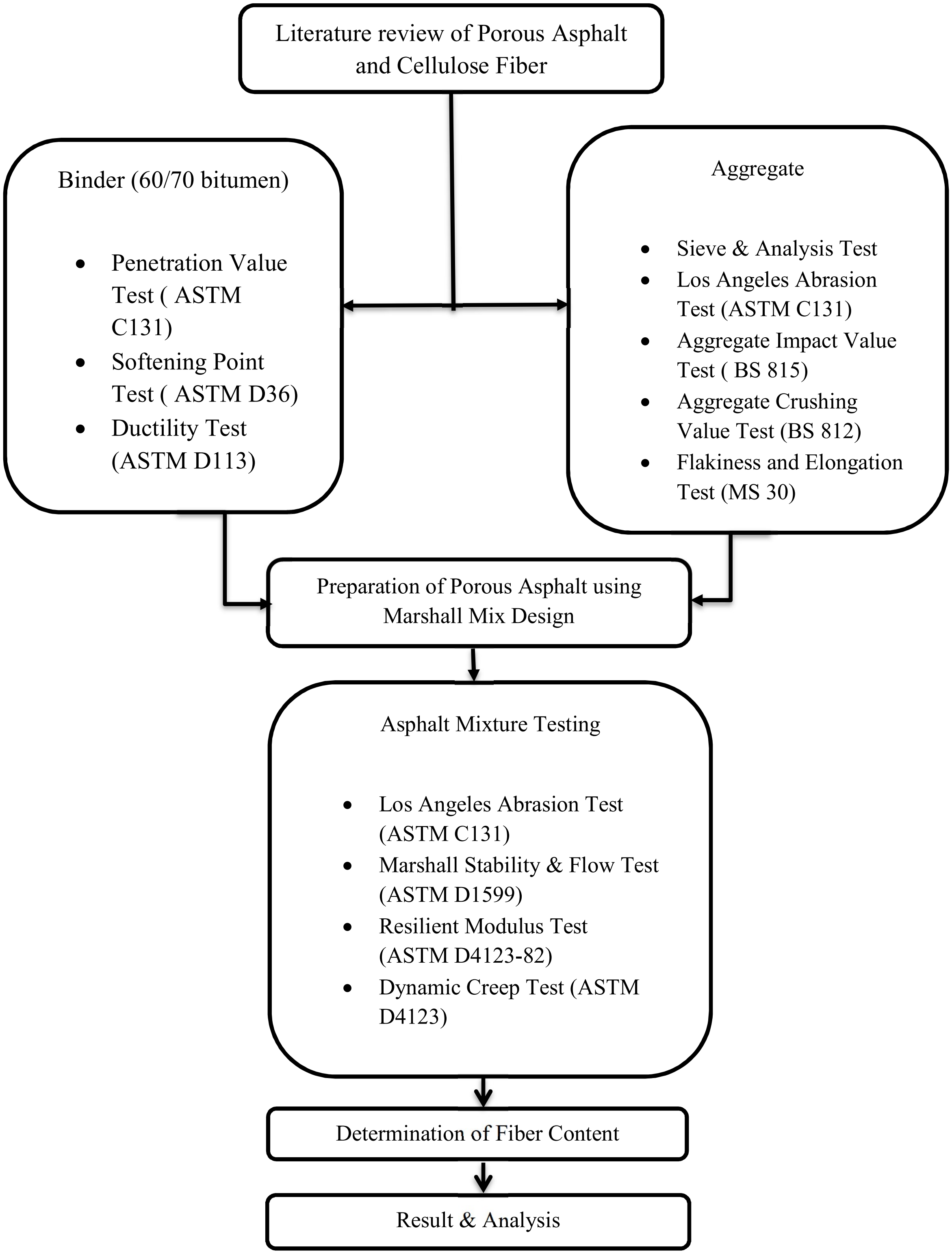


Figure 3.1 Flow Chart of the study

3.3 Material Testing

3.3.1 Bitumen

3.3.1.1 Penetration Value Test

The penetration test measures the consistency of asphalt binder. Thus, it can be classified into the standard grades. It was done by subjecting the asphalt binder sample in test cup of 55mm diameter and 35mm depth to penetration of a standard needle with a 100g mass for 5 seconds at 25°C. According ASTM C131, the average of penetration must in range 60 - 70 mm.

Procedure:

The asphalt binder was diluted for the specimen preparation by heating into the oven at the temperature between 75˚C to 100˚C for 15 minutes to 20 minutes. Next, the asphalt binder was poured into the penetration container. The specimens was cool in the open air for an hour to two hour at a room temperature. The standard penetration needle was cleaned before fix it into the needle holder and then, the needle was lowered slowly until its tip on the surface of the specimen. Meanwhile, the penetrometer dial reading was set zero and electric timer was attached to the penetrometer. Then, the button of timer was pressed start to release the needle holder for 5 seconds. The depth of penetration was recorded by taking the penetration value. The test were repeated for three readings on the same specimen in order to obtain the average penetration value. Lastly, the needle was cleaned after each time used. This test was conducted in accordance to the ASTM C131.

Calculation:

$$\text{Average Penetration Value} = \frac{Reading\ 1 + Reading\ 2 + Reading\ 3}{3}$$

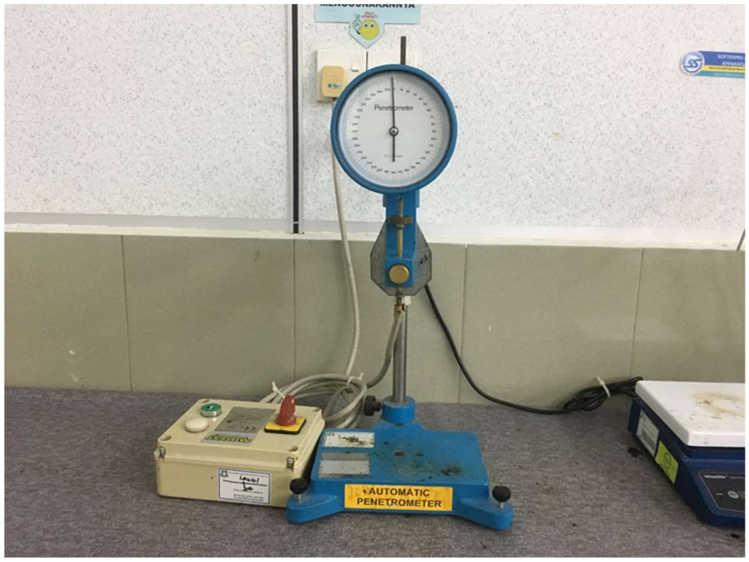


Figure 3.2 Penetration equipment

3.3.1.2 Softening Point Test

The softening test was conduct to measured the temperature at which asphalt binder reaches a certain degree of softness. It was done by the loading asphalt binder sample, which is confined in a brass ring, with a steel ball of diameter 9.5mm and mass 3.5g in a gradually heated water. The water temperature in ˚C which the sample softens and the ball strikes a plate 25mm below the ring is called the softening point of the asphalt binder. According ASTM D36, the temperature need in range 48 – 56˚C.

Procedure:

The asphalt binder that already softened was poured into the ring moulds. The specimens was cool in the open air for at least thirty minutes at a room temperature. Meanwhile, the water was poured into the beaker and then put into the water bath. The magnetic stirrer was put into the beaker. Then, the temperature of the water was measured by using a thermometer. The temperature of water was maintained at 5˚C ± 2°C for 15 minutes. Then, the specimens was placed in the ring holder once the stabilizing the temperature. After 15 minutes, the steel balls was placed in the ball-centering guides using forcep. Next, the water was heated at 5˚C ± 2°C per minute using the electric heater. Lastly, the temperature and the corresponding time was recorded after the ball drop at the base plate of the suspended ring holder. This test was conducted in accordance to the ASTM D36.

Calculation:

$$\text{Average softening point} = \frac{Temperature\ for\ Ball\ 1 + Temperature\ for\ Ball\ 2}{2}$$

Figure 3.3 Softening Point apparatus

3.3.1.3 Ductility Test

The test was intended to provide assurance that the bitumen is not too brittle to induce cracking in the bituminous road surfacing. The bitumen sample was subjected to elongation at a rate of 5cm per minute at 25^{o}C. According ASTM D 113, the minimum elongation of the sample is 100cm was called the ductility of bitumen.

Procedure:

The asphalt bitumen that already softened was poured into the standard briquette moulds in order to form the standard bitumen material specimens. After that, the specimen mould was cooled at room temperature for at least 30 minutes. The ductility specimen was immersed into the water bath and the temperature was maintained at 25° ± 0.5°C for 30 minutes. Then, the ductility specimens placed in a ductilometer after the ductility specimens have attained the desired temperature. The behaviour of the 'thread' of bitumen was monitored and the elongation was continued until the 'thread' was break up. Lastly, the respective distance in centimetre was recorded. This test procedure was carried out in accordance to the ASTM D113.

Figure 3.4 Ductility apparatus

3.3.2 Aggregate

3.3.2.1 Sieve Analysis Test

At every each type of bitumen mixture has a different grading limits. This is to ensure the mixture has a needed strength and characteristics for the specific pavement. The test was been conduct to separate the aggregates according the specific sizes. The procedure for this test was according BS EN 933-1:2012 as stated in JKR/SPJ/2008

Procedure:

The weight of sample approximately to 1100g was measured. The aggregate then was dried in the oven. Meanwhile, the sieve was carefully brushed to ensure all the loose was removed. Next, the sieve was combined into a stuck with the pan at the bottom, then the aggregate was poured into the top sieve and the lid was placed. Then, the sieve was placed into the mechanical shaker and the shaker was run for 10 to 30 minutes. Lastly, the sieve was removed, and the mass of aggregates retained on each sieve and pan was obtained.

Table 3.1 Gradation limit for Porous Asphalt Grading B

BS Sieve Size (mm)	**Percentage Passing by Weight (Porous Asphalt grading B)**
20	100
14	85 – 100
10	55 – 75
5	10 – 25
2.36	5 – 10
0.074	2 - 4

Figure 3.5 Mechanical shaker

3.3.2.2 Aggregate Impact Value Test (AIV)

The property of a material to resist impact is known as toughness. The aggregates are subjected to impact resulting in their breaking down into smaller pieces due to movement of vehicles on the road. So, the aggregate should have the sufficient toughness to resist their disintegration due to impact.

Procedure:

The aggregates sample was prepared by sieving the aggregates first and passing at 14.0mm and retained on the 10.0mm size was obtained. The aggregate was washed and then dried in the laboratory oven for not more than four hours at the constant temperature at 100˚C to 110˚C. Then, it was cooled at room temperature before run the testing. Next, the aggregates was filled into the smaller steel cylinders in three layers and by using the tamping rod the aggregates was tamped for 25 times for each layer. Then, the surface was level with tamping rod as straight edge in order to prepare the sufficient amount of the aggregates on the top layer. Next, the aggregates was transfer into the bigger mould and tamped 25 times again at every each layers. The weight of the cylinder plus the aggregates was weighted and recorded. After that, the sample was put in the apparatus and the hammer was released to fall freely on the aggregates. The sample then was subjected to a total manual-controlled 15 blows. The test aggregates sample then was removed from the mould and sieve through 2.36mm sieve openings. Lastly, the aggregates passing at the 2.36mm test sieve was weighted.

Calculation:

$$\text{Aggregate Impact Value} = (W1 / W2) \times 100$$

Where:

W1= Total weight of dry sample (g)

W2 = Weight of passing 2.36mm (g)

Figure 3.6 Aggregate impact value test apparatus

3.3.2.3 Aggregate Crushing Value Test (ACV)

The aggregate crushing value is a measure of resistance of the aggregates crushing under the gradually applied compressive load. Crushing value of aggregates indicates its strength. The lower crushing value is recommended for roads and pavements as it shows the lower crush fraction under the load and would give a longer service life. The aggregates used in roads and pavements must be strong enough to withstand the crushing under the roller and traffic.

Procedure:

The aggregates sample was prepared by sieving the aggregates first and passing at 14.0mm and retained at the 10.0mm size was obtained. The aggregate was washed and for not more than four hours the aggregate was dried in the laboratory oven at the constant temperature at 100˚C to 110˚C. Then, it cooled at room temperature before run the testing. Next, the aggregates was filled into the steel cylinders in three layers. Each layer of aggregates was tamped for 25 times by using the tamping rod. Then, the surface was level with tamping rod as straight edge in order to prepare the sufficient amount of the aggregates on the top layer. The aggregates sample was placed into the compressive machine and the load at uniform rate was applied for 10 minutes. Then, the maximum force applied was recorded. After that, the crushed material was removed into the tray and the aggregates was sieved using 2.36mm sieve. . Lastly, the aggregates passing the 2.36mm test sieve was weighted.

Calculation:

$$\text{Aggregate Impact Value} = (W1 / W2) \times 100$$

Where:

W1= Total weight of dry sample (g)

W2 = Weight of passing 2.36mm (g)

3.3.2.4 Los Angeles (LA) Abrasion Test

The Los Angeles abrasion value is to measure the degradation of aggregates resulting from a combination of action including abrasion, impact and grinding in a rotating steel drum containing steel spheres. After 500 revolution, the aggregates are sieved to measured the degradation as percent loss, which is the weight percentage of coarse material lost during the test as a result of the mechanical degradation. According ASTM C 131, the result not more than 25%.

Procedure:

The weight of sample was 5000g of aggregates including 2500 ± 10g of the size 20 to 14mm, and 2500 ± 10g of size 14 to 10mm was used. The aggregates was washed first and dried on the oven. Then, the aggregates was weighted before run the testing. The sample was placed in the LA Abrasion machine and 11 steel balls was added into the machine. Next, the drum was rotated for 500 revolutions at a speed of 30 to 33 rpm. After the drum was stopped, the aggregates was removed and the aggregate portion was sieved using size 1.70mm. Then, the sample that was retained on the sieve was washed and dried in the oven at a temperature of between 105° and 110°C for 24 hours. Then, the aggregates was taken out from the oven and cooled at the room temperature. Lastly, the aggregate was weighted immediately.

Calculation:

$$\% \text{ Abrasion} = \frac{W1 - W2}{W1} \text{ X } 100$$

Where:

W1 = the weight before abrasion

W2 = the weight after abrasion

Figure 3.7 LA abrasion apparatus

3.3.3 Cellulose Fiber

The binder used in this study was PEN 60/70 grade. The asphalt binder was mix with the Cellulose Fiber (CF) with increment of 0.2%, 0.3%, 0.4%, 0.5% and 0.6% of CF. The quantity of the each additive was selected by weight of asphalt binder.

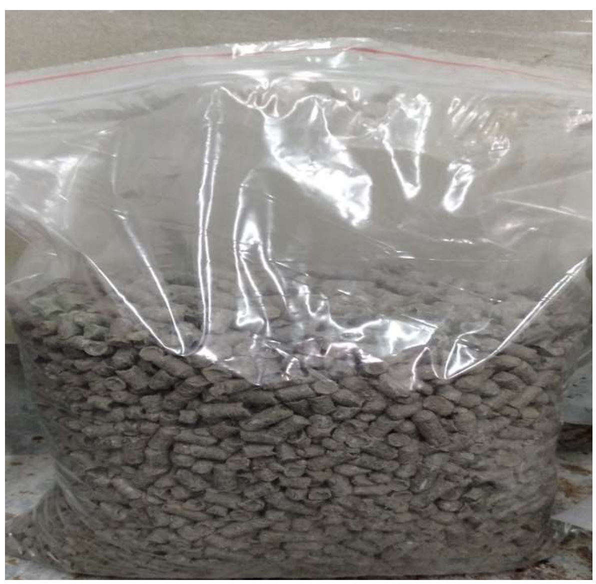


Figure 3.8 Cellulose Fiber

3.4 Marshall Mix Design

Marshall was conducted in order to prepare the standard specimens of Porous Asphalt for the determination of performance of Porous Asphalt in terms of Abrasion, Marshall Stability & Flow, Resilient modulus and Dynamic Creep.

Procedure:

The aggregate of 1100g graded according JKR standard were poured into the clean mould and dried into the laboratory oven at temperature 170˚C to 180˚C for at least 4 hours. Meanwhile, the bitumen were heated into the laboratory at the temperature 160˚C to 165˚C. Next, the aggregate were poured into the mixer and the mould were heated back in the laboratory oven. After the aggregate in the mixer reach at the temperature 130˚C to 160˚C, the binder was poured in the mixer. The mixture were mixed together until all the aggregate was coated. Meanwhile, a piece of filter paper spread with oil was fitted in the bottom of the mould. Then, the mixture was poured into the mould with different three layers and each layers were compact with 15 times. After that, the mould was placed in to the Marshall compacter machine and compacted the specimens in the mould with 50 blows at the both side. Lastly, the specimens was carefully removed from the mould and marked. There are 6 specimens for each percentage of Cellulose Fiber (0%, 0.2%, 0.3%, 0.4%,0.5% and 0.6%).

Figure 3.9 Compacted samples

3.5 Performance Test

The performance test were consists of four test which Los Angeles (LA) Abrasion Test, Marshall Stability & Flow Test, Resilient Modulus Test and Dynamic Creep Test.

3.5.1 Los Angeles (LA) Abrasion Test

LA Abrasion value was to measure the degradation of specimens resulting from a combination of aggregates with bitumen and Cellulose Fiber. After 300 revolution, the aggregates were weighted to measured the degradation as percent loss.

Procedure:

There are two specimens of Porous Asphalt for each percentage of Cellulose Fiber content were used. The aggregates were weighted before run the testing. Then, the sample was placed in the LA abrasion machine without the steel ball. Next, the drum was rotated for 100, 200 and 300 revolution. At every 100 revolutions, the drum was stopped and the specimens were weighted. Two specimens for each percent of Cellulose Fiber content were testing for LA Abrasion test.

Calculation:

$$\% \text{ Abrasion} = \frac{W1 - W2}{W1} \text{ X } 100$$

Where:

W1 = the weight before abrasion

W2 = the weight after abrasion

Figure 3.10 Sample before and after test of LA Abrasion

3.5.2 Marshall Stability & Flow

Marshall Stability & Flow was conducted to measure the resistance to plastic flow of cylindrical specimens of an asphalt pavement mixture loaded on the lateral surface by means of the Marshall apparatus.

Procedure:

The specimens was measured the height and weighted in air, water and saturated surface dry (SSD) conditions. The specimens weight in air condition were recorded. In water condition, the specimens was completely submerged in the water bath at temperature 25˚C for 3 to 5 minutes. Then, the weight by weighing in water was determined. After that, the sample was taken out and dried by blotting quickly with a damp towel and the weight in air was determined. Next, the specimens were immersed in a water bath for 30 to 40 minutes at 60˚C. the sample was removed and lightly dried with towel and placed between the lower and upper segment of the breaking head. The complete assembly was placed on the Marshall testing machine and the flow meter was adjusted to zero. Then, the maximum load and flow were recorded. Two specimens for each percent of Cellulose Fiber content were testing for Marshall Stability & Flow test.

Figure 3.11 Marshall testing machine

Figure 3.12 Sample before and after test of Marshall Stability & Flow

3.5.3 Resilient Modulus

The resilient modulus is non-destructive test used to measure the performance of pavement response to traffic loading. This test was conducted by measuring indirect tensile strength in repeated loading. The load was applied vertically in the vertical diameter plane of cylindrical specimens. The test was conducted at two different temperature which 25˚C and 40˚C.

Procedure:

The sample height and diameter was recorded and the samples were conditioned at 25˚C and 40˚C in the Universal Testing Machine (UTM) for 15 minutes before the specimens can be testing. Next, the specimens was placed into the loading apparatus and the loading strips was positioned to be parallel and centered on the vertical diametric plane. Then, the horizontal strain detector was adjusted by referring the electronic measuring system. The testing was started by applying repeated haversine load of 400N and subjected to 5 pulse. The specimens was tested twice which is 0˚C and 90˚C of rotation and 1000, 2000 and 3000ms. Lastly, the average of these value was taken as resilient modulus. Two specimens for each percent of Cellulose Fiber content were testing for resilient modulus.

Figure 3.13 Resilient modulus machine

3.5.4 Dynamic Creep

Dynamic creep is the destructive test to estimate the rutting potential of specimens. This test was conducted by using the Universal Testing Machine (UTM) in accordance with ASTM D4123. The test was conducted at two different temperature which 25˚C.

Procedure:

The sample height and diameter was recorded and the samples were conditioned at 25˚C in the Universal Testing Machine (UTM) for 15 minutes before the specimens can be testing. Then, the specimens was placed into the loading apparatus and the loading strips were positioned. The electronic measuring system were adjusted and balanced as necessary and LVDT's to operate within their range as viewed on the levels display and the closed the level display. Then, the jogged loading ram was down to contact with the top loading platen of creep jig but without applying any loading force. Then, pressed the start button and the sample was subjected to repeated application of loading pulse. The stress and deformation data were charted and tabulated as the test proceeds. Lastly, switch off the valve when the process achieve 3600 cycle. Two specimens for each percent of Cellulose Fiber content were testing for dynamic creep.

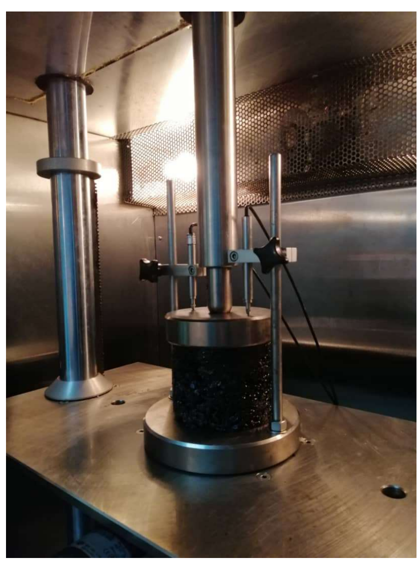


Figure 3.14 Dynamic creep machine

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, the results that were obtain from laboratory test are analysed to determine the performance of porous asphalt incorporating cellulose fiber.

4.2 Physical Properties

4.2.1 Aggregate Gradation of Porous Asphalt B (Sieve Analysis)

The total weight of the mixture per sample is 1100g. Table 4.1 below shows the aggregate gradation for PA Grading B samples.

Table 4.1 Percentage of Aggregate Passing

Sieve size (mm)	**Passing (%)**	**Retained (%)**	**Retained (g)**
20	100	0	0
14	85 – 100	7.5	82.5
10	55 – 75	27.5	302.5
5	10 -25	47.4	522.5
2.36	5 – 10	10	110
0.075	2 - 4	4.5	49.5
Pan	0	1	11
OPC	0	2	22

4.2.2 Aggregate Impact Value (AIV) Test

From the Table 4.2 below show the value of AIV test for the aggregate material is 14.64%. Therefore, according the Table 4.3, the aggregate can be classify as strong for pavement surface course.

Table 4.2 Result of Aggregate Impact Value

Aggregate size (mm)	**Weight of Aggregate (g)**			**% Loss**
	Before Test (M1)	**Retain at 2.36mm sieve (M2)**	**Passing at 2.36mm sieve (M3)**	
14 -10	293.66	25.16	43	14.64

Table 4.3 Classification of Aggregate Impact Value Based On JKR/SPJ/2008

Aggregate Impact Value (AIV)	**Classification**
< 20%	Exceptionally Strong
10 – 20%	Strong
20 – 30%	Satisfactory for Road Surfacing
> 35%	Weak for Road Surfacing

4.2.3 Aggregate Crushing Value (ACV) Test

The value of ACV test for the aggregate material is 11.96% and it is within the required limit less than 30%. The detail result is shown in Table 4.4 below.

Table 4.4 Result of Aggregate Crushing Value Test

Aggregate size (mm)	**Weight of Aggregate (g)**			**% Loss**
	Before Test (M1)	**Retain at 2.36mm sieve (M2)**	**Passing at 2.36mm sieve (M3)**	
14 -10	3000.24	2641.29	358.83	11.96

4.2.4 Los Angeles (LA) Abrasion Test

Table 4.5 below shows the result of LA Abrasion test for aggregate material. The percentage loss obtained is 21.18% and it is within the required limit of 10% to 45%. Therefore, this aggregate material are suitable for asphalt mix in term of abrasion strength.

Table 4.5 Result of Los Angeles Abrasion test

Aggregate size (mm)	**Weight of Crushed Aggregate (g)**			**% Loss**
	Before (M1)	**After (M2)**	**Loss (M3)**	
20 – 14	5001.4	3941.77	1059.63	21.18
14 – 10				

4.3 Binder Test

The binder test that have been conducted for asphalt binder PEN 60/70 was Ductility Test, Standard Penetration Test and Softening Point Test. For Ductility Test, the value of elongation binder obtained was 104 cm and according the specification, the minimum elongation binder for PEN 60/70 is about 100 cm. Therefore, the sample of binder was acceptable and able plastically deform without any fracture.

Table 4.6 shows the average of penetration value test for binder PEN 60/70. According the specification, the range of penetration value for binder PEN 60/70 is 60 mm to 70 mm. The softening point value test for binder that was use in this study and the result shows in Appendix A. The value of softening point obtained was 49.6℃ and thus, it was within the range of 48℃ to 56℃ for bitumen PEN 60/70.

Table 4.6 Penetration Test of PEN 60/70

Sample	**Penetration (mm)**			
	1	**2**	**3**	**Average**
A	59	66.98	64	63.33
B	67	75	68	70

From Penetration Index Nomograph shows in Appendix A, the relationship between the Penetration Test and Softening Point Test for bitumen PEN 60/70. Thus, according the Table 4.7, the bitumen PEN 60/70 can be classified as conventional paving bituminous material.

Table 4.7 Relationship between Characteristics of Bituminous Material and PI value

PI Range (Nomograph)	**Classifications**
PI ≤ -2	Temperature Susceptible Bituminous Materials (Tars)
-2 < PI < +2	Conventional Paving Bituminous Material
PI ≥ +2	Blown Bituminous Material

4.4 Mechanical Properties

4.4.1 Los Angeles (LA) Abrasion Test

In Appendix B shows the weight losses of sample before and after test abrasion. Table 4.8 shows the average percentage abrasion for unmodified PA and modified CF-PA. In general, the lower abrasion loss have better performance in term of abrasion losses.

Table 4.8 LA Abrasion for Porous Asphalt Grading B

NUMBER OF REVOLUTION	% of ABRASION LOSS					
	0% CF	0.2% CF	0.3% CF	0.4%CF	0.5% CF	0.6% CF
100	18.53	2.58	2.99	1.07	2.04	1.35
200	25.97	5.01	5.96	2.26	3.40	4.82
300	30.99	7.75	6.93	3.13	6.15	7.49

From Figure 4.1 prove the existence of CF in PA grading B give good impact toward performance of PA. Before CF adding into the asphalt mixture, the abrasion loss was 30.99% at 0% CF after finish 300 revolution but after added the CF into the asphalt mixture, the lowest abrasion loss was 7.49% at 0.4% CF.

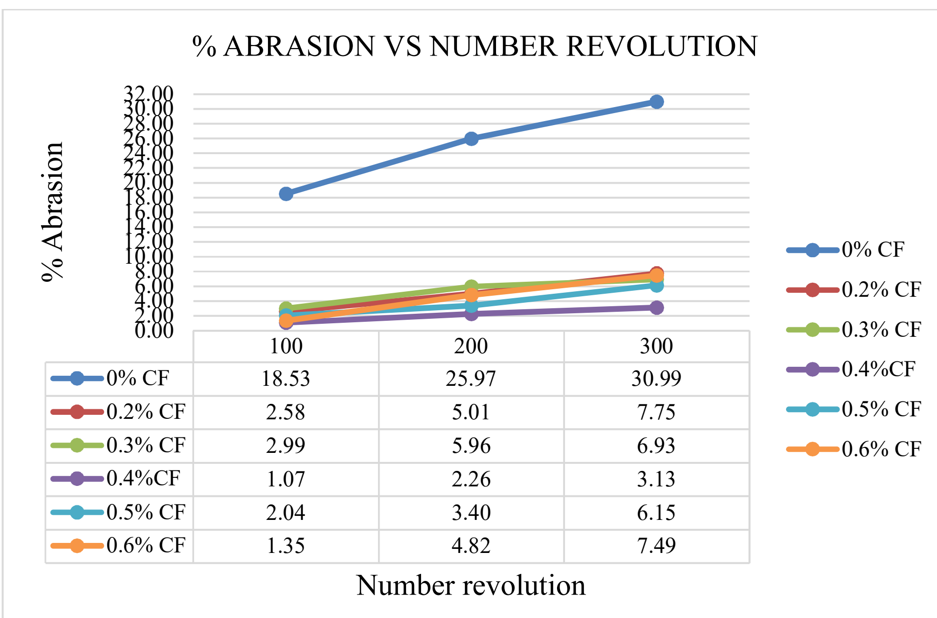
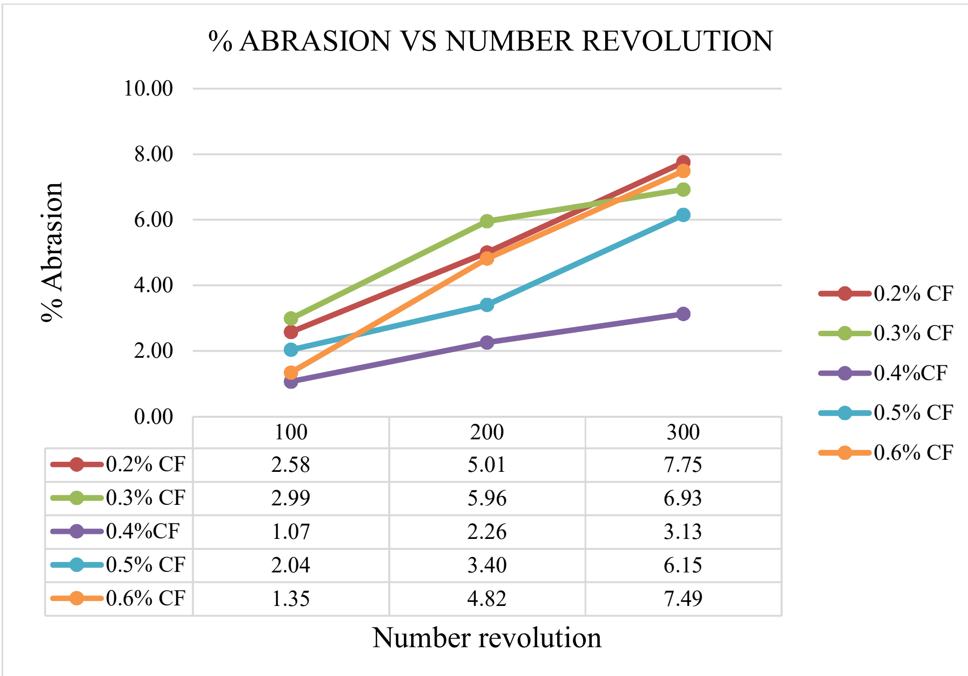


Figure 4.1 Unmodified PA and Modified CF-PA

Figure 4.2 shows the effect of different CF content towards PA grading B. It shows at 0.4% CF has the lowest abrasion value, 3.13% while 7.75% abrasion loss at 0.2% CF. Thus, it were seen when added CF into PA were improved 32.5% the performance of PA grading B in term of abrasion loss.



	100	200	300
0.2% CF	2.58	5.01	7.75
0.3% CF	2.99	5.96	6.93
0.4%CF	1.07	2.26	3.13
0.5% CF	2.04	3.40	6.15
0.6% CF	1.35	4.82	7.49

Figure 4.2 Modified CF-PA

4.4.2 Marshall Stability & Flow Test

4.4.2.1 DENSITY

Figure 4.3 shows the density of unmodified sample and modified sample with existence CF. Density is define as mass per unit volume. Based on the theory, the increasing density value of pavement will increasing the fatigue life, rutting resistance and durability. Thus, higher density of sample is important in order to prevent water penetrate to subgrade layer and leads to deterioration. Therefore, the bar chart showed the highest density happened at 0.6% CF while lowest at 0% CF. The result showed the existence of CF in PA can improved the performance of PA and from Table 4.9 showed at 0.6% CF content give higher percentage improvement, 2.04%.

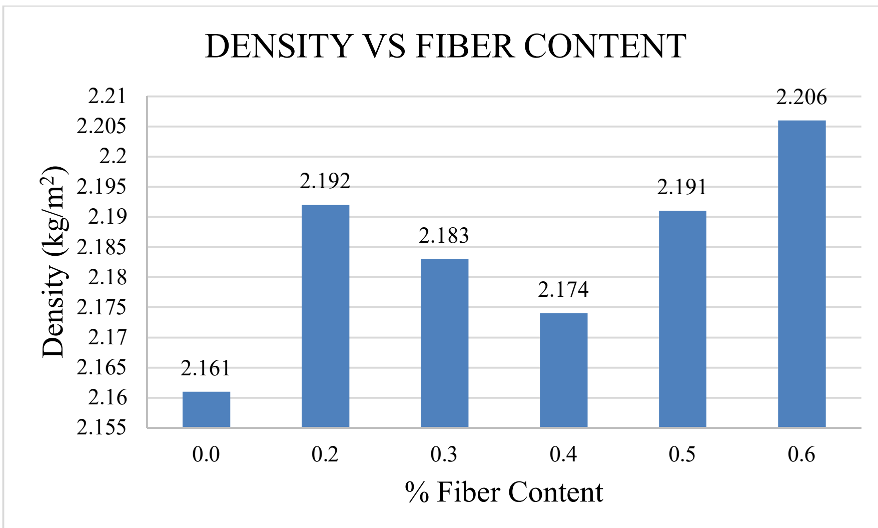


Figure 4.3 Density against CF content

Table 4.9 Percentage of improvement density

Cellulose Fiber Content	Density (kg/m^2)		% Improvement
	Control Sample (0.0%)	Modified Sample	
0.2	2.161	2.192	1.41
0.3	2.161	2.183	1.00
0.4	2.161	2.174	0.60
0.5	2.161	2.191	1.367
0.6	2.161	2.206	2.04

4.4.2.2 STABILITY

The result presented in Figure 4.4 indicate the average stability of two sample for unmodified sample and modified sample. In general, stability is means the maximum load applied before failure of sample happen. From that figure, all modified sample has higher stability compared to unmodified sample. The highest stability was at 0.6% CF (6732 N) compared to unmodified sample. The stability of pavement influenced by density and thus, the highest density were giving the more stability of sample. Based on the Table 4.10, the highest improvement of PA was at 0.6% CF content, 41.32%.

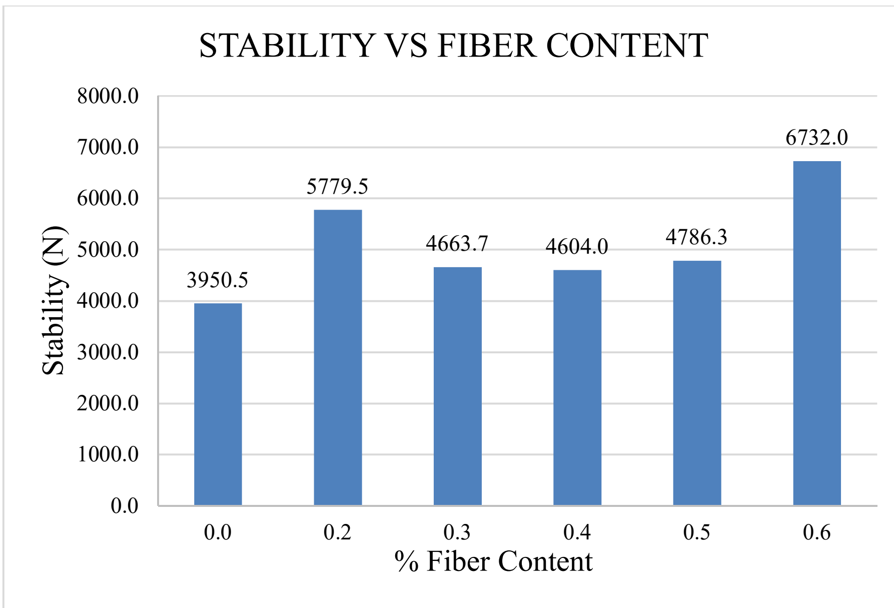


Figure 4.4 Stability against CF Content

Table 4.10 Percentage of improvement stability

Cellulose Fiber Content	Density (kg/m^2)		% Improvement
	Control Sample (0.0%)	Modified Sample	
0.2	3950.5	5779.5	31.65
0.3	3950.5	4663.7	15.29
0.4	3950.5	4604.0	14.19
0.5	3950.5	4786.3	17.46
0.6	3950.5	6732.0	41.32

4.4.2.3 STIFFNESS

Stiffness is means the stability over flow and it is used to determine the rutting effect. The stiffness have capability to withstand load without significant deformation occurred on the sample. Thus, higher stiffness were leads to higher strength of pavement but the stiffness should be at the optimum due to the brittleness will take place thus leads to cracking. Based on the Figure 4.5, the higher stiffness was at the 0.4% while the lowest stiffness was at the 0% CF and the percentage improvement when added 0.4% CF was 71.02%. Table 11 showed the percentage improvement for each percentage of CF content.

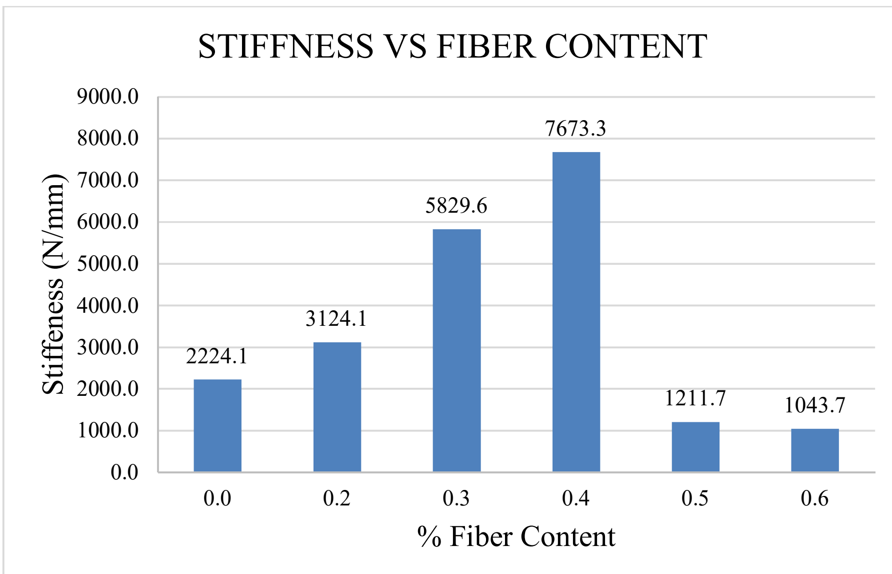


Figure 4.5 Stiffness against CF Content

Table 4.11 Percentage of improvement for stiffness

Cellulose Fiber Content	Density (kg/m^2)		% Improvement
	Control Sample (0.0%)	Modified Sample	
0.2	2224.1	3124.1	28.80
0.3	2224.1	5829.6	61.85
0.4	2224.1	7673.3	71.02
0.5	2224.1	1211.7	-83.55
0.6	2224.1	1043.7	-113.10

4.4.3 Resilient Modulus Test

Resilient modulus is to determine the resilient modulus of bituminous mixtures and connected by applying compressive loads. The samples were test at two different points and was conduct in accordance with ASTM D4123-82. Table 4.12 and Table 4.13 below shows the average value for resilient modulus at 25˚C and at 40˚C respectively obtained from Universal Testing Machine (UTM).

Table 4.12 Resilient Modulus for PA at 25˚

Cellulose Fiber Content (%)	**Average Resilient Modulus (Mpa)**		
	1000	**2000**	**3000**
0	1865	1864	1797
0.2	1430	1359	1350
0.3	1289	1298	1274
0.4	851	1501	1460
0.5	966	938	853
0.6	1988	2040	2056

Table 4.13 Resilient Modulus for PA at 40˚C

Cellulose Fiber Content (%)	**Average Resilient Modulus (Mpa)**		
	1000	**2000**	**3000**
0	781	702.5	660
0.2	744	724	676
0.3	802	711	700
0.4	818	746	629
0.5	818	930	909
0.6	974	926	898

Figure 4.6 and Figure 4.7 below shows the non-uniform result of resilient modulus against percentage of CF content at temperature 25˚C and 40˚C. The graph shows that the higher pulse repetitive loads, the lower the resilient modulus value. For result at temperature 25˚C, the highest resilient value obtained at 0.6% CF was 1988 MPa while for 0% CF was 1865 MPa at 1000ms pulse repetition.

At temperature 40˚C in Figure 4.7, the result shown the increasing of resilient modulus when added CF content but the value are lower than at 25 ˚C. At 40˚C (1000ms), the highest resilient value also obtained at 0.6% CF content was 974MPa and the lowest resilient value was at unmodified sample, 781Mpa. As well known, the higher temperature make the viscosity of binder decrease and then allow tit to flow within the mix and lose its ability to bind the aggregates.

Table 4.14 and Table 4.15 shown the percentage improvement of resilient modulus value at 25˚C and 40˚C at every CF content. The higher percentage of improvement at 25˚C was 6.18% and 19.82% at the temperature 40˚C.

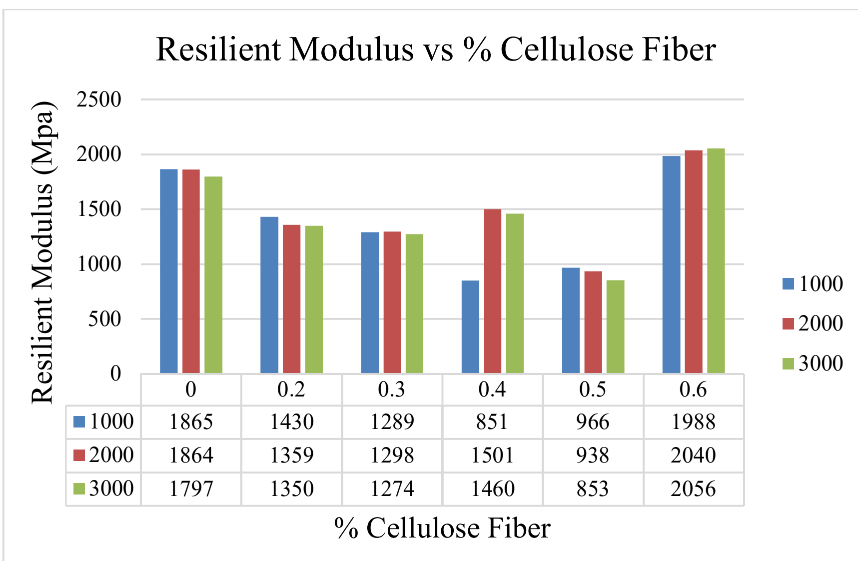


Figure 4.6 Resilient Modulus at 25˚C

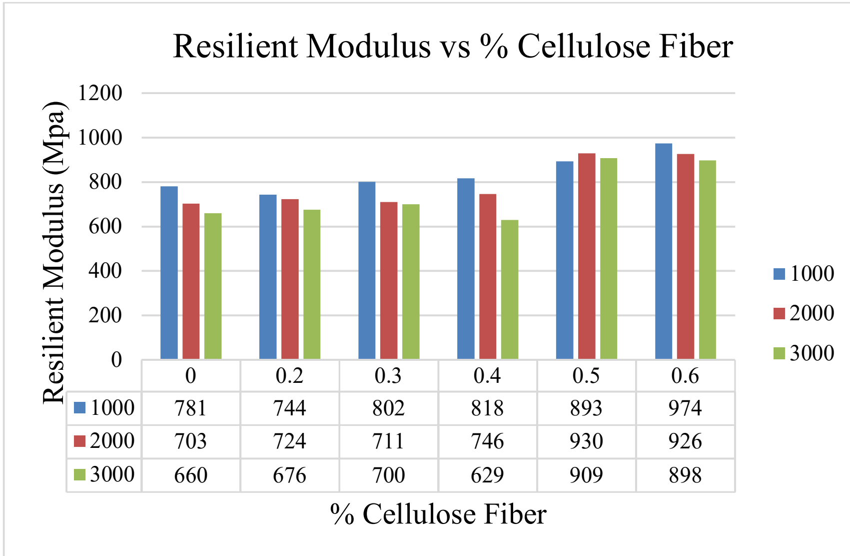


Figure 4.7 Resilient Modulus at 40˚C

Table 4.14 Percentage of improvement for resilient modulus at 25˚C (1000ms)

Cellulose Fiber Content	**Density (kg/m^2)**		**% Improvement**
	Control Sample (0.0%)	**Modified Sample**	
0.2	1865	1430	-30.34
0.3	1865	1289	-44.61
0.4	1865	851	-119.04
0.5	1865	966	-92.96
0.6	1865	1988	6.24

Table 4.15 Percentage of improvement for resilient modulus at 40˚C (1000ms)

Cellulose Fiber Content	**Density (kg/m^2)**		**% Improvement**
	Control Sample (0.0%)	**Modified Sample**	
0.2	781	744	-4.97
0.3	781	802	2.61
0.4	781	818	4.52
0.5	781	893	12.54
0.6	781	974	19.82

4.4.4 Dynamic Creep Test

Dynamic creep test is destructive test which were conducted by using Universal Testing Machine (UTM). This test were conduct to determine the rutting potential of asphalt mixture. Figure 4.8 shows the relationship between the cycle and strain for unmodified and modified sample at temperature 25˚C. Based on the graph, the existence of CF at 0.2%, 0.4% and 0.5% in PA give lowest strain compared with unmodified sample. From the table 4.16, the lowest value of dynamic creep was 6.66MPa at 0.2% CF content compared with another modified sample. Thus, the improvement value of PA was 55.99% between 0.2% CF content and control sample in term of dynamic creep when existence of CF in PA.

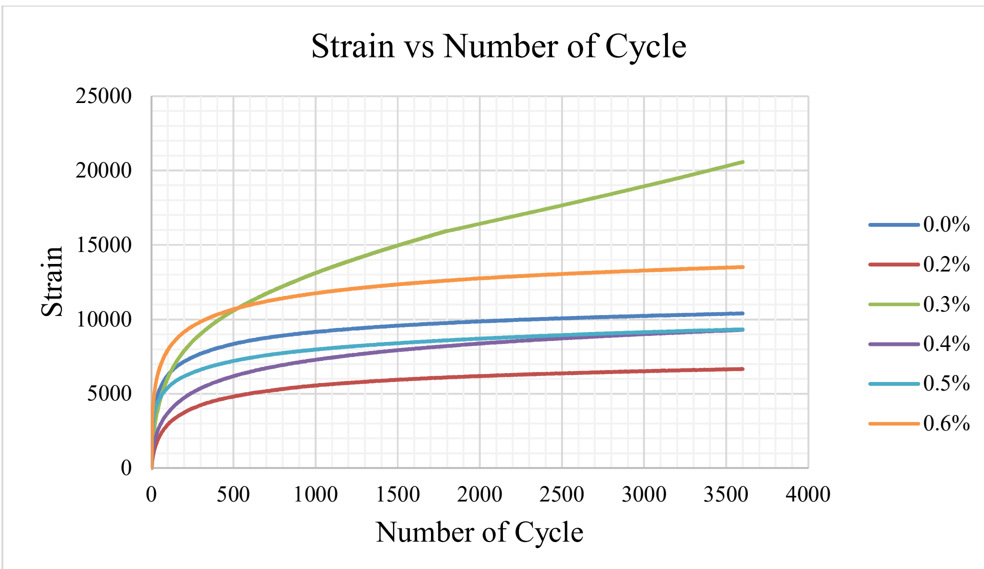


Figure 4.8 Dynamic Creep at 25˚C

Table 4.16 Result of dynamic creep

Cellulose Fiber Content (%)	Creep Modulus (MPA)
0.0%	10.40
0.2%	6.66
0.3%	20.58
0.4%	9.30
0.5%	9.32
0.6%	13.51

4.5 Optimum Fiber Content

Table 4.17 shows the ranking of performance PA at every laboratory test conducted to determine the optimum fiber content. The excellent ranking was describe by "1" while the worse was "6". The lowest total performance were be the optimum fiber content. Thus, 0.6% CF was the optimum fiber content due to its performance in abrasion, stability and resilient modulus were better than other percentage of CF content.

Table 4.17 Ranking of Optimum Fiber Content

Test	**0.0% CF**	**0.2% CF**	**0.3% CF**	**0.4% CF**	**0.5% CF**	**0.6% CF**
LAA	6	5	3	1	2	4
MS (Density)	6	2	4	5	3	1
MS (Stability)	6	2	4	5	3	1
MS (Stiffness)	4	3	2	1	5	6
RM (25˚C)	2	4	5	3	6	1
RM (40˚C)	5	6	4	3	2	1
DC	4	1	6	2	3	5
Total	**33**	**23**	**28**	**20**	**24**	**19**

CHAPTER 5

CONCLUSION

5.1 Introduction

This chapter discusses the conclusion that can be made from the test result obtained and also the recommendation to improve this study on Porous Asphalt (PA). The objective for this study is to evaluate the performance of PA incorporated with Cellulose Fiber (CF).

5.2 Conclusion

Based on the result and analysis, the following conclusion can be made:

1. The added of CF in PA showed the bigger different value of abrasion loss compared with unmodified PA. At 0.4% CF added into the asphalt mixture have the lowest abrasion loss, 3.13% compared to unmodified sample, 7.75%.
2. The performance of PA incorporated CF are various at different percentage based on Marshall Stability and Flow. Stability and density have higher value at 0.6% CF content while stiffness have lower value at 0.4% CF.
3. The result for resilient modulus at the both temperature, 25˚C and 40˚C shows at 0.6% was higher stiffness modulus compared with unmodified PA.
4. From the dynamic creep testing, it can stated that the sample for 0.2% CF is better than other modified sample because it have lower value of micro-strain compared to unmodified sample.

5. By using ranking of performance test, the Optimum Fiber Content (OFC) was at 0.6% CF.

5.3 Recommendation

Based on this study, the following recommendation can be made as follows:

1. Used other type of Cellulose Fiber (CF) such as loose form CF in order to hkown their stabilizing in PA.
2. The use of other types of fiber could be use such as synthetic fiber, to evaluate the different performance between different types of fiber.
3. The used of other type of additives should be investigate such as nano particles or polymer.
4. The use of different gradation of Porous Asphalt such as Porous Asphalt grading B to compare the performance with Porous Asphalt grading B.
5. Moisture Susceptibility Test should be carried out in order to evaluate the moisture susceptibility resistance of bituminous mixtures in dry and wet condition.

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APPENDIX A

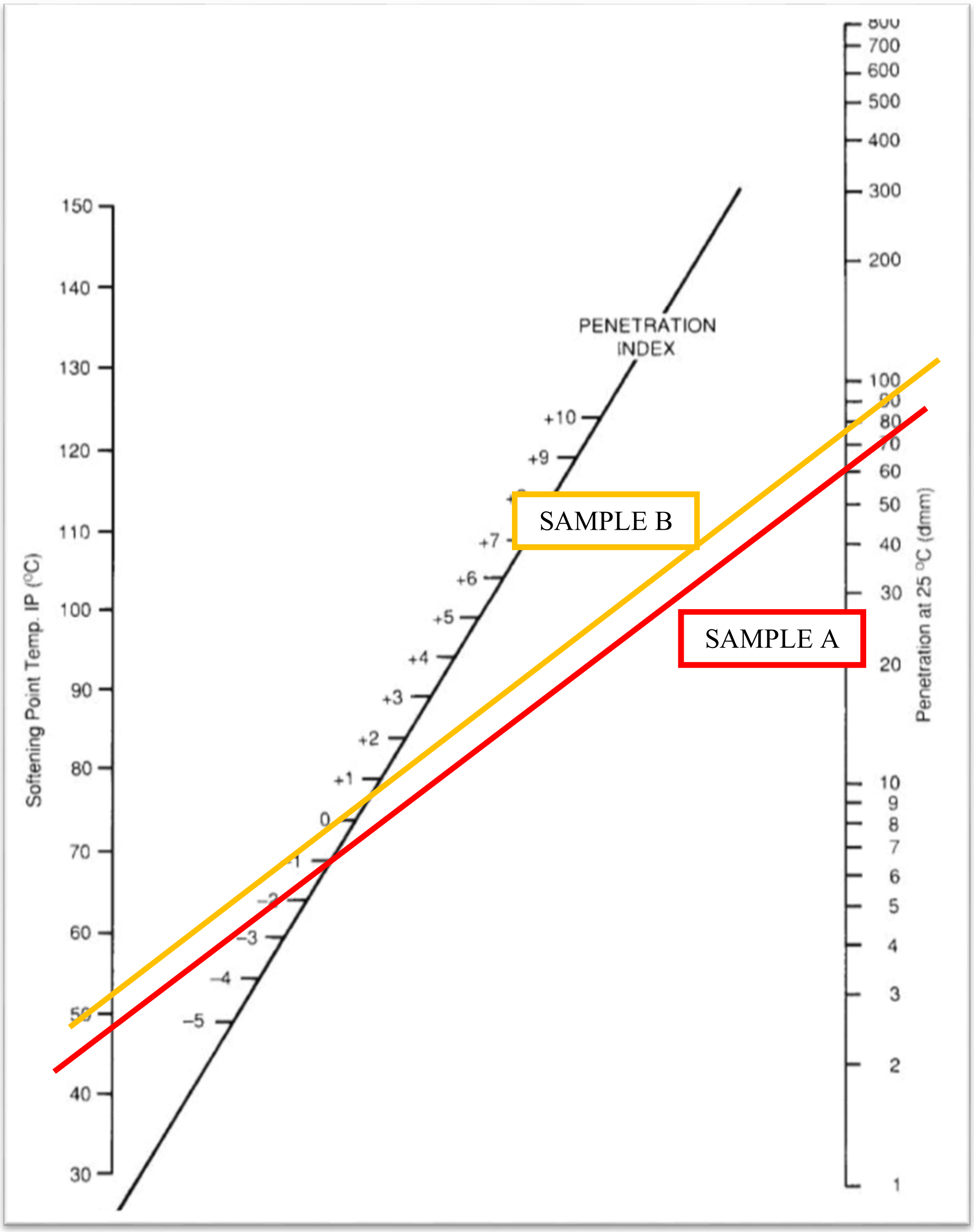
A.A (1) Softening Point for PEN 60/70

Time reading (minutes)	Temperature (℃)	Time reading (minutes)	Temperature (℃)
0	7.1	21	25
1	8.1	22	26.4
2	8.6	23	27.7
3	9.1	24	29.1
4	9.6	25	30.5
5	10.2	26	32
6	10.8	27	33.4
7	11.5	28	34.9
8	12.2	29	36.5
9	12.9	30	38.2
10	13.6	31	39.9
11	14.4	32	41.5
12	15.3	33	43.2
13	16.1	34	44.9
14	17	35	46.8
15	18	36	48.7 (Ball A drop)
16	19	37	50.5 (Ball B drop)
17	20	38	
18	21.1	39	
19	22.4	40	
20	23.7		

Average softening value = (48.7 + 50.5) / 2

= 49.6

A.A (2) Penetration Index Nomograph



APPENDIX B

A.B (1) Weight of sample before and after test abrasion

Sample	Weight of sample before,W1 (g)	Weight of sample after, W2 (g)		
		100 rev	200 rev	300rev
S1 (0%)	1067.28	716.92	578.77	508.77
S2 (0%)	1121.20	1066.04	1041.46	1001.46
AVERAGE	**1094.24**	**891.48**	**810.12**	**755.12**
S1 (0.2%)	1132.78	1114.07	1078.87	1028.69
S2 (0.2%)	1110.93	1071.72	1052.50	1041.03
AVERAGE	**1121.86**	**1092.90**	**1065.69**	**1034.86**
S1 (0.3%)	1109.55	1080.13	1047.25	1025.89
S2 (0.3%)	1133.30	1095.65	1061.95	1061.61
AVERAGE	**1121.43**	**1087.89**	**1054.60**	**1043.75**
S1 (0.4%)	1148.74	1134.02	1114.18	1104.60
S2 (0.4%)	1161.72	1151.70	1144.04	1133.49
AVERAGE	**1155.23**	**1142.86**	**1129.11**	**1119.05**
S1 (0.5%)	1152.31	1124.54	1101.13	1047.32
S2 (0.5%)	1164.86	1145.40	1137.17	1127.30
AVERAGE	**1158.59**	**1134.97**	**1119.15**	**1087.31**
S1 (0.6%)	1154.71	1131.24	1063.82	1020.27
S2 (0.6%)	1166.07	1158.30	1145.10	1126.72
AVERAGE	**1160.39**	**1144.77**	**1104.46**	**1073.50**