PERFORMANCE OF POROUS ASPHALT INCORPORATING STEEL FIBER

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ABSTRAK

Asfalt berliang (AB) merupakan salah satu jenis turapan lentur yang dikenali sebagai turapan yang mempunyai keupayaan kebolehtelapan yang direka bentuk untuk mengawal air hujan dan mengurangkan air larian permukaan. Walau bagaimanapun, struktur adalah tertakluk kepada kerosakan dari keretakan, aluran, pelucutan dan penuaan pesat di bawah kesan beban kenderaan yang berulang di atas jalan raya, cuaca panas dan hujan lebat. Penggunaan gentian keluli manfaat dalam usaha meningkatkan kekuatan, tempoh hayat dan ketahanan turapan jalan kerana gentian keluli cenderung digunakan untuk kawalan retak dan mengukuhkan laluan itu dengan menentang tegangan keretakan. Oleh itu, tujuan kajian ini adalah untuk menilai prestasi campuran asfalt berliang dengan gentian keluli dan mengatasi masalah atau isu yang berkaitan dengan AB. Campuran mengandungi peratusan gentian keluli yang berbeza-beza dinilai untuk menyemak sampel yang memberikan prestasi yang terbaik mengikut keperluan dengan menggunakan ujian makmal LA lelasan, Resilient Modulus, kestabilan Marshall dan aliran dan Rayapan dinamik. Hasil kajian menunjukkan bahawa penambahan 0.6% gentian keluli memberi nilai yang paling rendah lelasan, manakala 0.5% kandungan serat menyumbang nilai tertinggi resilient modulus dan marshall kestabilan serta 0.3% untuk rayapan dinamik. Dengan kaedah peringkat atau kedudukan, kandungan gentian keluli yang optimum dapat dikenalpasti. Campuran PA diubah suai dengan gentian keluli menghasilkan peningkatan prestasi AB sebagai bahan permukaan jalan raya. Kesimpulannya, bahawa campuran asfalt yang mengandungi gentian keluli boleh meningkatkan kestabilan dan kekuatan campuran. Untuk kajian masa depan, ia adalah disyorkan untuk menganalisis kesan pelbagai panjang gentian keluli terhadap prestasi asfalt berliang dan prosedur reka bentuk yang sesuai bagi campuran asfalt berliang yang akan menyebabkan prestasi memuaskan AB semasa perkhidmatan.

ABSTRACT

Porous Asphalt (PA) is known as highly permeable asphalt surface that design to be permeable pavements for storm water control and reduce the storm water runoff. However, the structure is subjected to damage from cracking, rutting, stripping and rapid aging under the effects of repeated vehicle loading, hot climates and heavy rainfall. Application of steel fiber benefit in increasing the strength, life period and toughness of road pavement because steel fiber tend to be used to control of crack and strengthen the pavement by resisting tensile cracking. Thus, the aim of this study is to evaluate the performance of these porous asphalt mixtures with the steel fiber and overcome the issue that is related to PA. A mixture contains varying percentages of steel fiber were assessed to check which samples gives the best performance as per the requirement by using laboratory tests which is LA Abrasion, Resilient Modulus, Marshall Stability and Flow and Dynamic creep. The results show that the additions of 0.6% steel fiber give the lowest value of abrasion, while 0.5% fiber content contributes the highest value of Resilient Modulus and Marshall Stability respectively. While 0.3% fiber content is the best for dynamic creep. By ranking method, the optimum fiber content of 0.6% is obtained. PA mixtures modified with steel fiber produce the performance enhancement of PA as a road surfacing material. It is concluded that the asphalt mixtures containing steel fibers could be increases the stability and strength of the mix. For future studies, it is recommended to analyze the effect of various steel fiber length towards porous asphalt performance and an appropriate design procedure for porous asphalt mixture that will render the satisfactory performance of PA during service.

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LIST OF SYMBOLS

PA	Porous Asphalt
ENG	Engineering
AIV	Aggregate Impact Value
SMA	Stone Mastic Asphalt
ACV	Aggregate Crushing Value
OPFC	Open Graded Friction Course
OPA	Open Graded Asphalt
SMA	Stone Mastic Asphalt
DGA	Dense Graded Asphalt
SF	Steel Fiber
LA	Los Angeles

LIST OF ABBREVIATIONS

PA	Porous Asphalt
ENG	Engineering
AIV	Aggregate Impact Value
SMA	Stone Mastic Asphalt
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OPFC	Open Graded Friction Course
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DGA	Dense Graded Asphalt
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LA	Los Angeles

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Porous Asphalt (PA) or known as Open Graded Friction Course (OGFC) is a highly permeable asphalt surface that act as a storm water management. The mixtures contain more coarse aggregates than fine aggregates. This PA is different from other types of asphalt because the water can penetrate into the pavements from surface into a recharge bed and permeate into the soils below the pavement. PA also has been verifying their quality since the mid-1970s (James, G, et al, 2016). This design can contribute profitable and worthwhile storm water management systems.

Fiber is an essential or fabricated material that has longer length than it is wide. It has been used in various areas including in the construction field. The fiber can be in many forms such as steel, polymer or natural materials. It also designed as substances that can upgrade the material properties, strengthening of pavement, resistance towards impact, flexural strength, decisiveness, fatigue protection and have good endurance. Moreover, Ahmed, S.A and Mahmood, O.T (2015) studied on the influence of mineral fibers properties. The study concluded that fiber can produced additional tensile strength and at times fibers are added to balance the bitumen during mixing and preparation of the samples.

Asphalt pavement has been used in roadway for a long time. Because of the heavy loading pavement distresses can occur like stripping, ravelling, cracking and moisture damage due to water penetrate through porous asphalt. When there is presence of water, the bonding between aggregate and bitumen will become weakens so the moisture damage can happened. While water ponding is when water is unable to drain away caused by lack of water runoff toward the drain. Besides that, heavy traffic loads tends to affect the performance of asphalt mixture in term of its resilient modulus. Therefore, this research is to assess the accomplishment of porous asphalt incorporating steel fiber and overcome the issue that is related to porous asphalt.

The result of the research will conclude the advantage of steel fiber existence in reducing the issues of pavements. Among the advantage of fiber is to assure pavement strength, and fiber may be combined to the mixtures to boost the performance, control shrinkage, have longer pavement life, raise structural stability, and increasing rut resistance.

By using steel fiber as a modifier, the mixtures will be tested so as to determine the optimum fiber content of fiber modified porous aphalt.in order to recover the performance of porous asphalt. Therefore, in this study, type of fibers that we used is steel fiber which would help to achieve the better performance of pavements. Steel fiber also would have a lot of influence towards improving the properties of PA.

1.2 PROBLEM STATEMENT

Pavements in road always exposed to the heat and precipitation throughout the day. Therefore, a chance to the damage of the pavements will be high especially when the structure is reacting toward the presence of water. Fluids are one of the weaknesses for common asphalt mixtures. Therefore, when water penetrates through asphalt, the pavements will face a deficiency for instance moisture damage, rutting, stripping and water ponding. After heavy rain, water ponding tend to happened because of lack of water runoff toward the drain so the water unable to drain away. Besides that, massive traffic loads lean to influence the accomplishment of asphalt mixture in term of its flexible modulus. Therefore, a way to overwhelm this distress behaviour is by adjusting the asphalt by the properties. Hence, fiber have a tendency to deliver enhancement of properties for construction material and this analysis envisioned to endorse fiber-material as additives in order to recover the properties of asphalt mixtures.

1.3 OBJECTIVE

1. To evaluate mechanical performance of steel fiber modified porous asphalt.

2. To determine the optimum fiber content of steel fiber modified porous aphalt.

3. To evaluate the performance of porous asphalt incorporating steel fiber in terms of abrasion, Marshall Stability and Flow, Resilient Modulus and Dynamic creep.

1.4 SCOPE OF RESEARCH

For this study, the asphalt binder will be 60/70 PEN for unmodified sample while PEN 60/70 with steel fiber was used for the modified sample. Porous asphalt mixtures were ready by adding steel fibers as an additive in the mixtures. A total of 48 samples were ready for porous asphalt mixtures at different percentages of fiber content ranging from 0% to 0.6% and the 0% as a reference between modified and unmodified asphalt samples. The requirement that will be used for this research is in accordance to Malaysian Public Work Department for road works (JKRSPJ2008).

To plan the mixtures, Marshall Mix Design technique will be used and lead to resolve the volumetric properties and carry on with the best possible asphalt binder content. Among the test of asphalt binders is including penetration test at 25^{o}C, softening point test and ductility test that were carried out. From penetration test we can know the rigidity and constancy of asphalt binder before it may be applied on street. To decide the temperature at which given asphalt binder reaches a certain points of softness and get the result for flow and constancy of asphalt binder can be known from softening point test. In addition, ductility test is to illustrate the ductility of asphalt binders.

Next, from Marshall Mix design, we can prepare the samples in order for determination of firmness and flow in the Marshall equipment and to decide density, fractions of air voids, percentage of density and percentage of aggregate voids fulled with binder. There are four tests for performance which is Cantabro test, Marshall Stability and flow test, resilient modulus and Dynamic creep that involve in identifying the optimum fiber content for the best performance of asphalt.

1.5 SIGNIFICANCE OF RESEARCH

Steel fiber is type of metal filaments wire that deformed and produces into a discrete length. This steel fiber is obtained by manufacturing process and has different types of shape or cross sections. It mostly used as an additive to alter or increase the performance and properties of the bituminous materials in a good way. Since long ago, people use this fiber technology to help in enhance the performance of the bituminous materials and built durable pavements. Steel fiber appears in a metallic colour with different types of appearance like hooked ends, flat ends, indentation or straight and also has excellent stability, high surface area, high tensile strength and can be easily dispersed. By adding fibers like steel fiber normally will recover the tensile strength of asphalt samples and recovers the rutting and fatigue resistance of asphalt mixtures. It also can recover strength and durability and decrease permeability.

Based on the previous study, it has state that the steel fiber applied in a reinforcing of the concrete structure as concrete strengthening. It also said that these fiber materials reside in the low prices and in the high functioning features. With the addition of steel fiber in the asphalt mixtures, the tensile strength of steel fiber modified asphalt will increases the toughness. It also will recover the recovery ability of asphalt mixtures. Thus it is capable in enhancing the properties of porous asphalt.

CHAPTER 2

LITERATURE REVIEW

2.1 HISTORY OF PAVEMENT

Pavement is a road surface with durable surface material. The function is to convey loads to the sub base and underlying soil. This surface path is use especially for a public area and pedestrians alongside or sidewalk. These days, with an existing of pavement, a path network has been developed. There are many path networks that can connect to the different places. Therefore, paths are the primary route of transportation for carrying belongings and person. Road which made up from pavement had been design from Romans, Macadam, and Telford era since a decade ago. They are among the early people into asphalt and Portland cement concrete pavement. (Gordon, K.R, 2016) stated that in year 1982 is when the first concrete pavement design is built in the street. The advancement of pavement has been started from the beginning and will emphasize more than other parts of the world.

Roman roads were the first era that build and up hold a path system according to Tillson in 1990. It was estimated that the Romans built about 87,000 km of roads within their empire. At that time, the main reason they built a path is for military purposes that linked the camp which were around 30 km apart. Therefore, the roads were straight and without regard to grade of path. In this stage, the path consists of four layers generally from the top to bottom of layers. The top layer is surfacing that consist of polygonal blocks bedded in underlying layer with a smooth surface. Then, a gravel and sand with lime cement as a base for the second layer. For third layers, there were composed of rubble masonry and small stone set in lime mortar and the last layer will be a courses of flat stones set in lime mortar and function as a subgrade.

Next is Telford era, they build roads on relatively flat grades surface so as to decrease the number of horses needed to haul cargo. Basically, they build the roads as a path for horses. The pavement is about 350 to 450 mm in depth and consists of three layers (Snyder, M.B, 2016). The bottom part of layer is comprised of large stones and on top of that, two layers of stones with maximum size of 65 mm are on it. Then, follow by a wearing course of gravel.

The next generation is on Macadam era where they built a sloped subgrade surface to recover drainage which are different or not the same like Telford. But, this road is simpler than other era. It consists of two layer angular aggregate on top of the subgrade and the wearing course was located to provide an efficient ride for wagon wheels. At that stage, macadam pavements were considered only suitable for light traffic and not for urban path. The binder they used is coal that deposit from coal gas lighting. Possibly, this is one of the initial exertions to recycle waste resources into a pavement.

These days, there are two types of road surface based on design considerations and the loads that distributed to the subgrade which is flexible and rigid pavements. Among perfect road surface, it should cross the requirement like structurally strong to endure all kinds of pressures, have a long lifespan with low maintenance rate, and sufficient constant of friction to stop slipping of vehicles. However, simply creating is not enough to get a good type of pavement. It has to be deliberate wisely because a roadway that does not design properly will be worsens fast.

2.2 TYPES OF PAVEMENT

Pavement is located above the subgrade and underneath any wearing surface. For urban area, the pavement is bordered by kerb and channel while in the rural area is by road shoulders. This pavement can be categorized based on structural presentation and include of two types which are flexible and inflexible pavements. Both will distribute load in different trend over a subgrade.

2.2.1 Flexible Pavement

Flexible pavements comprise sand and gravel compressed with bituminous materials that contain of a mixture of asphaltic or bituminous material and aggregate. The structural performance for this pavement is when the wheel loads are conveys to the lower layers by interaction of the aggregate through the coarse structure. The structure of the pavement can either be bends or deflect due to traffic load because of the flexible surface course. The load will spread over a smaller zone and the stresses will drops with the depth.

The concept of layered system had been used for this pavement. It consist of a series of layer including the surface of pavement that has excellence quality materials, which is subgrade, sub-base course, base course, binder course and surface course. There is also a prime coat, seal coat and tack coat between base, binder and surface course. The highest coating of pavements should use the greatest materials to bear maximum compressive stress from the vehicles and the lower layers will encounter lesser magnitude of stress and low material can be used. Therefore, the top layer is most important to use a mixture that have self-healing properties due to heavier wheel loads and keep below allowable stress. This pavement also has less flexural strength than rigid pavements.

Furthermore, the subgrade strength and its stability depend upon the aggregate interlock, particle friction and cohesion. Nevertheless, it is also good pavements that can sustain temperature variations, so changes in atmosphere do not effect and create stresses in flexible pavements. The cost of installation for flexible pavements is lower and after 24 hours it can be used for traffic. While the maintenance cost is quite higher and need to keep up the maintenance after every 10 to 15 years. Without maintenance, the pavements can worsens rapidly, cracks and potholes likely to seem because of poor drainage system and packed traffic.

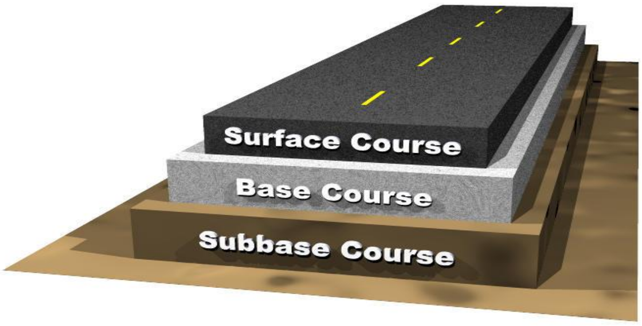


Figure 2.1 Cross section of flexible pavements

2.2.2 Rigid Pavement

Rigid pavement is different kind of pavement because it consists of one layer Portland cement concrete slab with relatively high flexural strength. This pavement is made up from cement concrete or reinforced concrete slabs. For load distribution, it will convey the wheel load stresses to a larger zone below and to subgrade soil by flexural strength of the pavement. It have structural cement concrete slab of adequate strength to resist the load from wheel loads and traffic. A flexural strength of concrete is a major factor for the design. The design in rigid pavement consist of four layers from the top to bottom which is subgrade, sub-base course as a choice, base course and concrete slab. There will be longitudinal and transverse joint on the surface of the pavements.

Next, the structural toughness is provided by the pavement slab itself by its beam action. It has stiffness and high modulus of elasticity to spread the load over wider zone or space of soil. In term of temperature, this pavement is not temperature variations friendly because the changes in temperature will induce heavy stresses in inflexible pavement. Also, if pavements deformations occurred due to wheel loads, the settlements will be permanent. The cost of installation can be a slight expensive than flexible pavement because it was stiffer and can have reinforcing steel. By using reinforced steel also can reduce or eliminate joints generally because high stiffness tends to distress load to a wider area. Besides that, it has lower maintenance cost which is good because available of cement. The concrete path also has a long life span and easy.

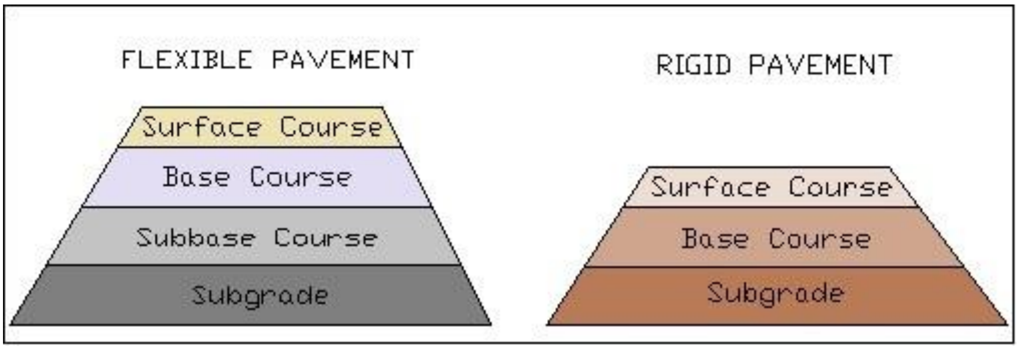


Figure 2.2 Different of cross section between flexible and rigid pavements

2.3 TYPES OF FLEXIBLE PAVEMENTS

2.3.1 Porous Asphalt

Porous asphalt pavements are known as highly permeable asphalt surface that also called as open graded asphalt. It only used crushed stone and very small proportion of sands. The primary purpose of the design is to be water permeable pavements for storm water control and reduce the storm water runoff. It can be design as infiltration or detention systems. Infiltration helps in recharge groundwater and helps base stream flows and porous asphalt pavement has high voids that reason a water to filter. Constructed over a stone filled reservoir to accumulate and store storm water and let it to permeate into the soil.

The use of this porous asphalt is at the light duty parking facilities, light duty roadway, local roads, trails and others. The total percentage of crushes stone has been used for strength and stability of pavement. For this kind of asphalt, there will be no maintenance treatments. This design can diminish contamination and replace pricey detention and treatment facilities. It was permeable to allowing free flow of water to subgrade for infiltration or other routing. They also lean not to exhibit cracking and pothole.

The advantages of open graded asphalt is recover runoff quality, sustainability, long life through proper maintenance and less costly. It also give benefits in reduction of spray on higher speed roads, reduction of hydroplaning, reduces the noise of the tires and prevent the pollution by eliminating surface runoff. The disadvantages are the pavement should be inspected regularly to avoid from surface clogging especially after large storms to maintaining the surface porosity. Pavement surface can be lashed or jet washed and for the damage it can be repaired by using non porous patching mixes.

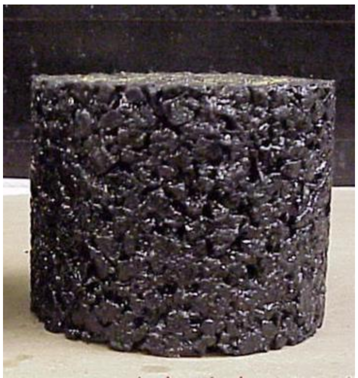


Figure 2.3 Example of Porous Asphalt

2.3.2 Dense Graded Asphalt

Dense graded asphalt is also known as well graded asphalt mixture is impermeable structures that allowing water to run away from surface areas. It has been refer as dense graded asphalt because of their nominal maximum aggregate size. This type of asphalt can be classified into two groups which is either fine graded or coarse graded. For fine graded, it has more fine and sand sized particles while has more coarse aggregate than fine is for coarse graded which is the opposite to fine graded. This type of asphalt, work well for structural, friction, levelling and patching needs. Dense graded asphalt has a great performance and suitable for all pavements layers. Pedestrian, residential, car park, state roads, or light industrial is the application of the dense graded asphalt in flexible pavements.

Among the advantage of dense graded asphalt for fine graded is has lower permeability, workability, thinner lifts, greater durability for low volume roads and has a smooth texture. For coarse graded, it allows thicker lifts and increased macro texture. Dense graded asphalt also can be designed to meet variety of applications and has lower initial cost. While there is also the disadvantages for dense graded asphalt which is the mixtures cannot accommodate high asphalt contents without becoming unstable and susceptible to rutting. Therefore dense graded mixtures usually use low amounts of asphalt that make them more susceptible to cracking and more permeable. Also, the texture of dense grade surface mixtures is relatively low where can affect wet weather traction.

2.3.3 Stone Mastic Asphalt

Stone mastic asphalt or sometimes called as gap graded asphalt is use to maximize rutting resistance and durability of the pavements. This gap graded asphalt creates stone on stone contact within the mixture because of more large aggregate in the mixtures. It was also more expensive asphalt than typical dense graded asphalt because of its requirement which requires more durable aggregate, higher asphalt content, modified asphalt binder and fibers. Fiber is one of additive use to help in inhibit binder drainage during mixing, transport and placing. This gap graded asphalt is used for surface course on high volume traffic. Based on the study from (Irfan, M et al, 2019), SMA mixtures can help in fatigue resistance and cracking due to higher binder content in the mixtures.

Among the gain of using stone mastic asphalt is lower tire noises due to coarser surface texture, less severe reflective cracking, and increase safety due to impressive friction capabilities with tires. (Irfan, M et al, 2019) also stated that SMA mixtures supposed to provide stability and rutting resistance because of the interlace of the aggregates. It also benefit in wet weather condition because of friction provided due to coarser surface. For stone mastic asphalt high quality of materials is required. Cubical, low abrasion, crushed stone, and manufactured sand are recommended to use because the mixtures will gains most of its strength when aggregates are all in contact or stone on stone aggregate concept. The aggregates also should have high polish values to retain good skid resistance where stone mastic asphalt is the final surface of the pavements. Rut resistance also relies on aggregate properties rather than asphalt binder properties. Strong aggregate provide by coarse aggregate that give a great resistance to permanent deformation. Highly durable pavement can happen because of loaded mastic that fills the voids in between those particles. By being a permeable type, a heavy tack coat or sprayed seal is required to waterproof the underlying surface. Because of that, the cost will be more expensive than typical dense graded asphalt. Thus, it was recommended to be used on high volume interstate highways because high costs and also because of durability and endurance.

Figure 2.4 Example of SMA mixtures

2.3.4 Polymer Modified Asphalt

The usage of polymer modified asphalt pavement materials for sustainable pavement system is recovers in permanent deformation, fatigue and low temperature cracking. This flexible pavement usually use for carrying high volumes of traffic. The properties of polymer modified asphalt is depends on the polymer characteristics and content of bitumen itself. Osman et al (2016) state that cracking in path can occurs at an intermediate and low temperatures and permanent deformation can occurs at high temperatures. These distresses will reduce the life of the pavement. Permanent deformation or rutting can occur in the flexible pavements when wheel loads cause higher stresses than the strength of the materials used to build the pavement. That’s why bitumen is required to have high stiffness at high temperature to resist rutting. Besides that, Saeed et al (2008) explore the uses of fibers as additive materials for the pavements.

An addition of fiber like polymer can lead to big changes to mixture properties. Polymer modification seems to be the best solution to recover asphalt properties but there is also a flaw which is poor asphalt polymer compatibility which will influences the stability of the system, higher viscosity during asphalt processing and application and higher cost. Sharma et al, 2012 show that the physical properties of asphalt binder when modified with polymers do not altering the chemical nature of it. Furthermore, this modifies will enhance overall presentation in any conditions and under wheel loads.

2.4 OVERVIEW OF POROUS ASPHALT

Porous asphalt also known as open graded friction course (OGFC) and absorbent type of asphalt. This type of porous asphalt permits water to gutter through the pavements surface into a stone recharge bed and infiltrate into the soils below pavement. There are many gains that we can get from porous asphalt mixtures which are as a surface water management and can eliminate costly drainage systems.

Porous asphalt also was designed to improve surface frictional resistance, minimized hydroplaning, reduced splash and spray, improved night visibility, rapid drainage of surface water, low traffic noise, increased visibility of traffic signs as well as low glare reflections in compactly populated and frequently travelled zone (Xu et al, 2018 and Alber et al, 2018). Nevertheless, as porous asphalt is a large-absorbency of asphalt and aggregates interlocked structure, disasters in porous asphalt are typically presented in the form of ravelling, cracking or a combination of them (Xu et al, 2018).

2.5 FIBER

2.5.1 History of fiber

Fibers are short discrete materials that have been used since ancient times as reinforcement. At that period of time, fibers were used in concrete as a replacement of reinforcement in building materials. Fibers include cellulose fiber, bamboo fiber, glass fiber, steel fiber and others. Each of the fiber has different properties that help in improving construction material. (Carlos et al, 2019) stated that fibers have on condition that have higher modulus, resistance, durability and deformation capacity and hence with more ductile behaviour. Therefore, the addition of fibers in asphalt improves the mix properties and contributes to sustainability by extending its service life and reducing path maintenance. While steel is assist in increase the Marshall stability, rutting resistance, indirect tensile strength and self-healing properties (Carlos et al 2019). He also mentioned that fiber-modified asphalt mixtures in which fibers have been used to deal with the main flexible pavement problems, such as rutting, fatigue cracking, thermal cracking and ravelling.

Moreover, one of the major objectives of using fibers in asphalt mixtures is not only to improve the fatigue and rutting performance, but also to increase ravelling resistance and moisture susceptibility (Tanzadeh et al, 2019). At the end of the study, we will be able to evaluate the mechanical performance of porous asphalt so as to achieve objective. Thus, the aim of this study is to evaluate the performance of these porous asphalt mixtures with the steel fiber and overcome the issue that is related to porous asphalt.

2.5.2 Types of fiber

Cellulose fiber is a commonly additives used in asphalt mixtures. It is a part of original plant or natural fibers that through a few process to produce the end product. It has shape or appearance like a cotton ball. Irfan.M et al(2019) said that cellulose fibers will help in high mix stability, improve strength and less drainage if use ad a stabilizing agent. Dungani, R et al (2019) cellulose fibers have been used in other industrial sectors such as automobile structural parts, marine, aerospace, packaging, and building materials where light weight is required. Previous study by Dungani et al reported that cellulose fibers were suitable for reinforcement in composites and to overcome the weakness in flexural, tensile and impact strength.

Next, Bamboo fiber is a stiff fiber that extracted from natural fiber plant. It was effectively less cost compare to other fiber because Bamboo plant is easy to found. Wiwoho, M.S et al (2017) stated Bamboo is mostly used to recover water catchment in other countries. Bamboo itself has been used in different field like food, handcraft and building construction. From previous study, they concluded that these type of fiber has high strength, greater tensile, flexural and impact strength. However, there is few weakness of bamboo which is a relatively short life span due to exposure to environmental changes, so the use of bamboo as a structural element should be capillary shield which is the fibers that give strength to the bamboo. Another author also said that the use of bamboo fiber provides only a small amount of compressive strength, since bamboo has a high wear and tear and shrink rate, and lower structural strength than conventional aggregates.

Furthermore, glass fiber also known as glass wool or fiberglass is a versatile material due to its light weight. It consists of various fine fibers of glass. These fiber produced by melt the silica sand, limestone, kaolin clay and other minerals until it changed into a liquid form and then the filaments coated with a chemical solutions. Glass fiber structure is stiff and strong in tension and compression and robust material because of its long and narrow structure but unfortunately it easy to buckle and weak in shear. Solanki and Pitroda, 2013 has stated that their high ration of surface area to weight is suitable for thermal insulators and in terms of tensile, the strongest is the thinnest fibers because it’s more ductile. They also certain the more the surface is scratched, the less the resulting tenacity. By using glass fibers as additives the final structure will increase concrete tensile strength and compressive. According to Nguyen et al, (2013) strong and flexible glass fiber reinforcement implement the axial stiffness required to redirect crack energy.

Last but not least, steel fiber can be defined as discrete, short length of steel having ration of its length to diameter in the ratio range of 20 to 100 with any of that and that are adequately small to be easily and randomly dispersed in fresh Marshall mix using conventional mixing procedure throughout the porous asphalt (Garcia et al, 2014). The ration range is the ratio between fibre length and its equivalent diameter. Huang et al. (2006) described steel fibers is conductive additives that improved the performance of hot mix asphalt mixtures and compromised the cracking resistance. Sercan Serin (2012) also investigates the optimum fiber content for steel fibers with different percentage of steel fiber and gets the best stability value. The result of the study showed that by adding steel fiber as an additive gives positive stability impact.

Figure 2.5 Cellulose fiber

Figure 2.6 Bamboo fiber

Figure 2.7 Glass fiber

Figure 2.8 Steel fiber

2.6 OVERVIEW OF STEEL FIBER

In the early 1900s steel fibers have been used in construction material. But in the previous, the shape of steel fiber was straight with smooth surface and the length of steel fiber will be cut or chopped. There are many different types of fiber either hooked ends, rough surfaces, or crimped. Steel fiber was factory-made from drawn steel wire, from slit sheet steel or by the melt-extraction process which produces fibres that have a crescent-shaped cross section. Bhat, K.M.U.D and Khan, M.Z, (2018) have found that different type of fibers added in specific percentage to concrete can improves the mechanical properties, durability and serviceability of the structure. In this study, by varying the percentage of steel fibers in asphalt, we can decide the optimum fiber content of the pavement that provides best performance. Therefore, the percentages of fiber content ranging from 0%, 0.2%, 0.3%, 0.4%, 0.5% and 0.6% will be used in this research respectively.

Also, from previous study, it has been observed that with the increase in fiber content up to the optimum value specific advantages will help in increased resistance to cracking, toughness, increased ductility and fatigue life. Steel fibers are a good fiber that compatibility with bitumen and have a good workability because it is flexible and easy to mix as fiber material is robust to withstand the preparation of samples. Alsaif et al (2018) studies showed that the results of incorporating steel fiber will reduced the risk of cracking and recover abrasion, spalling and impact resistance. Excellent stability, low cost, high surface area, and increases in flexural strength will be gain when used this fibers. Therefore, we can conclude that the uses of steel fibers increase their compressive strength and directly relate to volume fraction of steel fiber used.

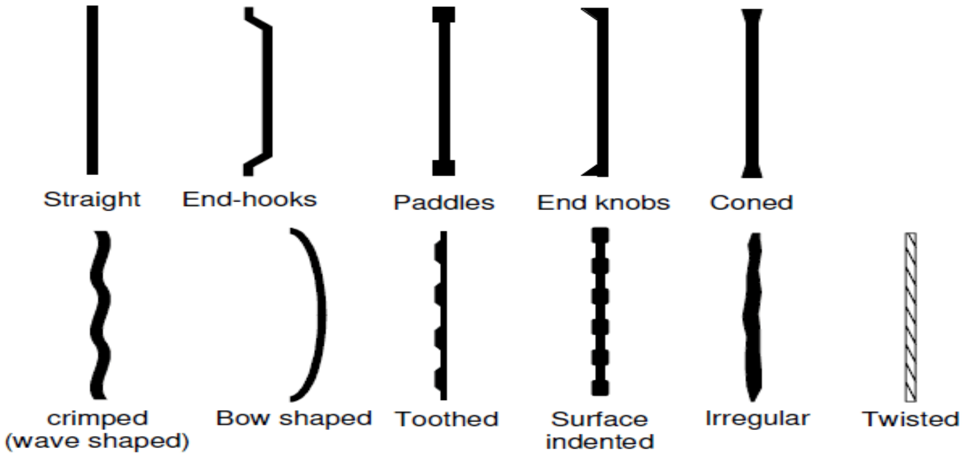


Figure 2.9 Different shape of steel fibers

Figure 2.10 Steel fiber

Figure 2.11 Shapes of steel fibers

2.7 PERFORMANCE OF POROUS ASPHALT

Porous asphalt pavement has a large void appearance that can see on the surface of the asphalt mixtures. Therefore, the water will drains into the pavement surfaces and penetrates through the soils and pavement structure. However because of its large voids, porous asphalt will be affected by ravelling, brittle cracking, and pitting. According to (Zhang, H et al, 2018) the porosity is crucial to the ecological functions of open graded friction courses like water drainage. This wearing course would give profit to the environment by reducing the noise because of sound absorption potential of the porous asphalt. Alvarez et al. (2009) mentioned that by using porous asphalt, noise level can be reduced by approximately 3 dB compared to dense asphalt. (Hamzah, M.O et al, 2010) described that porous asphalt was used in Malaysia to recover traffic safety and drainage system because Malaysia dealing with wet and humid tropical climate that have high rainfall intensity and he also stated that the number of accidents in Malaysia is decrease since used this type of pavement that somehow advertise the safety for the path users.

CHAPTER 3

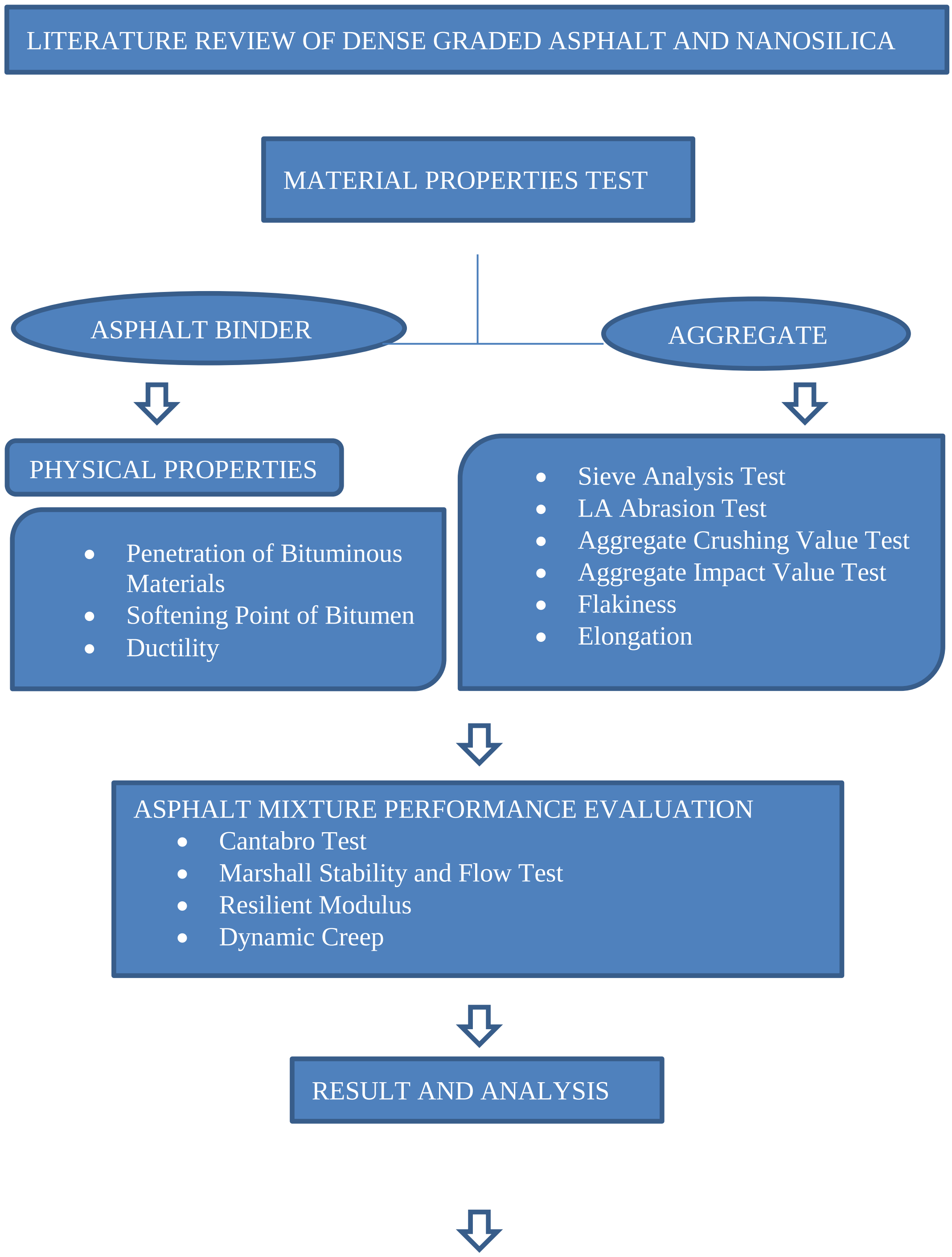
METHODOLOGY

3.1 INTRODUCTION

Among the material properties testing that were carried out in this research is asphalt binder and aggregate test. In this study, penetration grade that were used is PEN 60/70 grade. For aggregate test, it is consist of sieve analysis test, LA Abrasion test, aggregate crushing value test, aggregate impact value test, flakiness and elongation. After that, for asphalt binder there will penetration of bituminous materials test, softening point of bitumen test and ductility that should be carried out. Continue, after all material properties test is done, we can continue with the determination of optimum fiber content of porous asphalt using Marshall Mix Design method. Specimens of porous asphalt will be ready by using different percentages of fiber content within the range of 0% to 0.6% for PA. After it was done, we can continue with the mixture testing which is to know the performance of porous asphalt in terms of Cantabro test, Marshall stability and flow test, Resilient modulus and Dynamic creep test. After that, result and analysis can be made from the test.

3.2 FLOW CHART OF RESEARCH

Based on the figure below, the flow chart for the test that included in this research was showed. Started from the literature review as a reference and continue with the aggregate testing, asphalt binder testing and mixture testing.



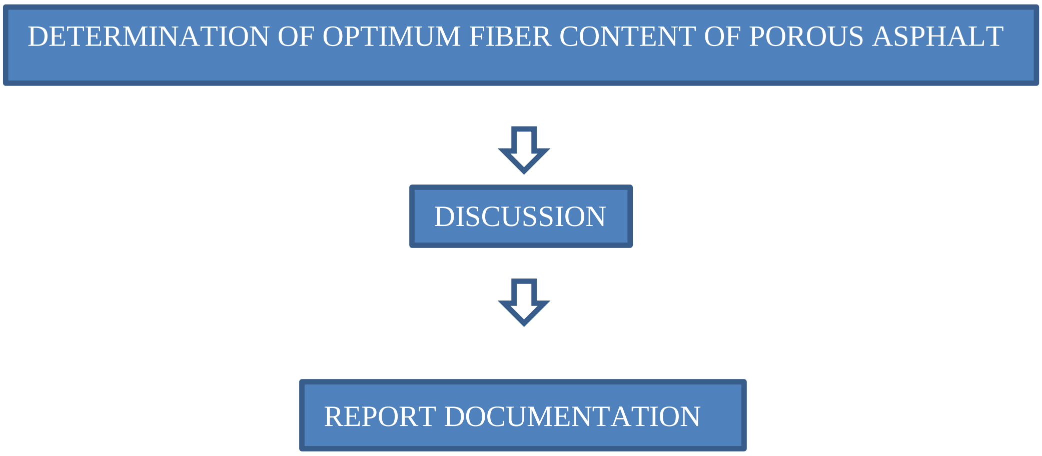


Figure 3.1 Flow Chart of Research

3.3 AGGREGATE TESTINGS

3.3.1 Sieve Analysis

The aggregates mix that will be used in sieve analysis test is PA. Among the equipment that will be used is:

i. Sieve set sizes (Pan, 2.36, 5.00, 10.00, 14.00, 20.00, 37.5)mm
ii. Balance
iii. Mechanical sieve shaker
iv. Oven

Procedures:

1. Prepare and dry the sample in the oven at the temperature of 110 ± 5^{o}C for 24 hours.
2. The sample is mix homogeneously and form it in con shape before reducing it to 500gm by using the quarter method.
3. Prepare a stack of sieve set where the larger opening will located on the top of the rest of sieves.
4. The sample is placed inside the sieve and put it in turn on mechanical sieve shaker for 15 minutes.
5. Separate the aggregates according to the sizes of gradation limits in AC14.
6. Measure the weight of sand retained in each sieve

Figure 3.2 Mechanical Sieve Shaker

3.3.2 Los Angeles Abrasion Value Test

This method is use to indicate aggregates toughness and to obtain the Los Angeles number in the form of percentage wear of aggregates which reflects their resistance to degradation using Los Angeles testing machine. The equipment that involved is stated below:

i. Los Angeles Abrasion machine
ii. Metal tray
iii. Sieve set sizes
iv. Steel spheres
v. Sieve shaker
vi. Balance

Procedures:

1. The test sample is wash and oven dry at 105 to 110^{o}C to substantially constant weight.
2. Place the test sample and the steel spheres in LA Abrasion Machine.
3. Switch on the machine to rotate the machine for about 500 revolutions at 30 to 33 rpm.
4. After being rotated, discharge the sample onto a tray and sieve on no.12 sieve.

5. Wash the sample retained on the sieve and dried at the temperature of 105 to 110^{o}C. the weight of the sample is taken after the sample is cooling down.

Figure 3. 3 Los Angeles Abrasion Machine

Figure 3.4 Steel Balls

3.3.3 Aggregate Impact Value Test

The purpose for this test is to determine the aggregate impact value of road stone.

Equipment:

i. Impact testing machine
ii. Tamping road
iii. Sieves set sizes
iv. Balance
v. A cylinder measure
vi. Oven

Procedures:

1. The aggregate is sieve and obtain the portion passing 14mm and retained on 10mm sieve
2. Wash and dry the aggregate at a constant temperature of 105 to 110^{o}C and then cool the sample.
3. Weight the aggregate
4. Fill the aggregate in the cylindrical measure in 3 layers, tapping each layer 25 times with the tamping rod.
5. Level the surface tamping rod as a using the straight edge.
6. Weight the aggregate in the measure.
7. Transfer the aggregate from the cylindrical measure to the cup in 3 layers and compact each layer by tamping in 25 strokes with the tamping road.
8. Release the hammer to fall freely on the aggregate. The test sample is subjected to a total of 15 blows.
9. Remove the aggregate sample from the cup and sieve through 2.36mm sieve.
10. Weight the fraction passing the sieve 2.36mm.

Figure 3.5 Impact Testing Machine

3.3.4 Aggregate Crushing Value Test

To determine the mechanical strength of the aggregate.

Apparatus:

i. Open ended steel cylinder of nominal 150mm internal diameter with plunger and base plate
ii. A tamping rod
iii. Balance
iv. Standard sieve of sizes 14.0mm, 10.0mm and 2.36mm beaker
v. Compression testing machine which is capable of applying force of 400kn
vi. Cylindrical metal measures

Procedures:

1. Filled the aggregates in thirds into the cylinder where each third is subjected to 25 blows from the tamping rod and weight the samples.
2. The surface of the cylinder is levelled and the plunger is inserted
3. Sample is placed between the platens of the testing machine and is loaded in a uniform rate so that the required 400kn is reached in 10 minutes.
4. Released the load and removed the crushed material.
5. Sieve through 2.36mm sieves and weight the fraction passing the 2.36mm.

Figure 3.6 Open ended steel cylinder with pluger, tamping road and compression testing machine

3.4 ASPHALT BINDER TESTING

3.4.1 Penetration of Bituminous Materials

Apparatus:

i. Penetration needle
ii. Water bath
iii. Penetration container
iv. Asphalt sample
v. Thermometers
vi. Penetrometer

Procedures:

1. Specimens are ready in sample containers and placed in a water bath at the prescribed temperature of test 1 hour before the test.
2. Clean the penetration needle and fix it into the needle holder and guide.
3. Low the needle slowly until its tip just makes contact with its image on the surface of the sample at right angles.
4. Set the penetrometer dial reading to zero.
5. Release the needle holder to penetrate the bitumen while the temperature of the specimens is maintained at 25^{o}C.
6. Read and record the depth of penetration.

Figure 3.7 Penetrometer

3.4.2 Softening Point of Asphalt Binder

Apparatus:

i. Steel ball of diameter 9.53mm and weighing 0.05g
ii. Tapered ring made of brass
iii. Ball guide and Ring holder
iv. Thermometer
v. Beaker
vi. Burner

Procedures:

1. The bitumen was melted and pour the liquid into a pair of ring placed on plate.
2. Thermometer is place in the center of ring holder levelled with the bottom of the ring
3. After specimen has cool, ring is suspended in the distilled water in the beaker at $5^oC \pm 2^oC$. bath temperature is maintained at that temperature for 15 minutes.
4. Put the steel balls on the surface of the bitumen in the ring.
5. Stirred and heated the bath liquid to $5^oC \pm 2^oC$ per minutes.
6. Temperature is noted just after the ball is passes and dropped into the base plate.

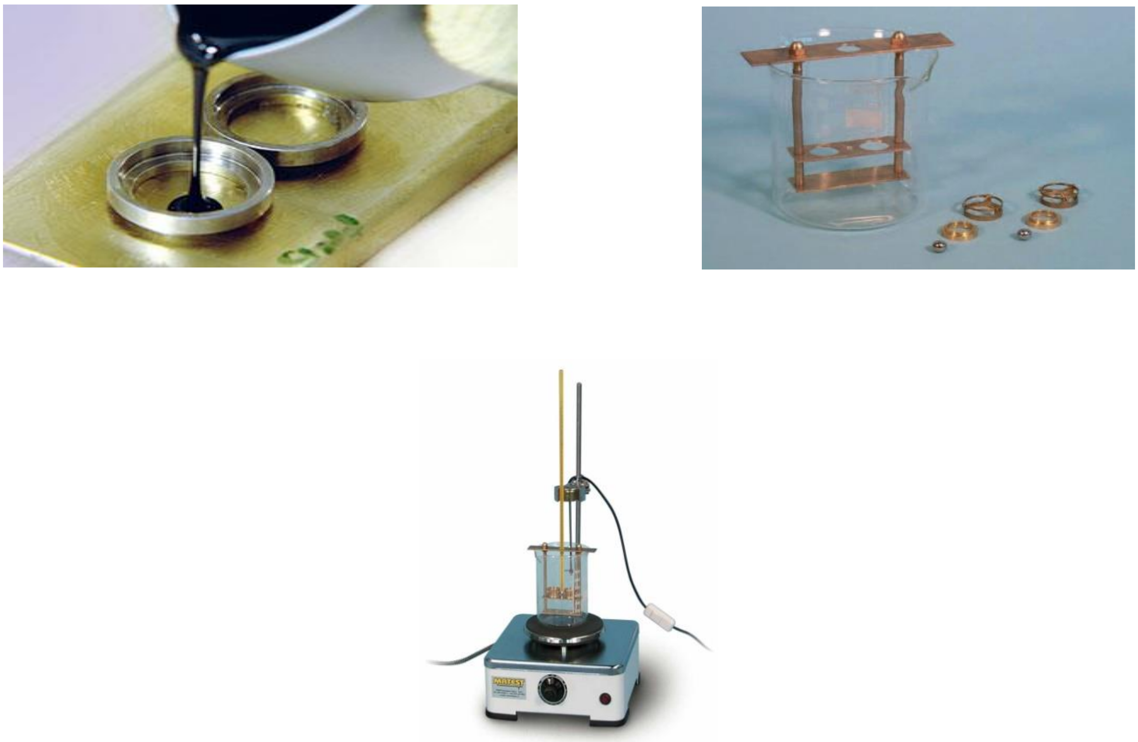


Figure 3.8 Apparatus of Softening point of bitumen

3.4.3 Ductility

Apparatus:

i. Testing machine
ii. Mould made up of brass
iii. Water bath

Procedures:

1. Unless otherwise specified this test shall be conducted at a temperatures of 27°C.
2. Melt the bitumen to be tested to a temperature of 75 to 1000 C above its approximate softening point till it becomes fluid.
3. Assemble the mould on a brass plate and coated on all the sides with a mixture glycerin and dextrin of equal parts to avoid sticking of the material.
4. Fill the mould until it is more than level full.
5. In filling the mould, pour the material in a thin stream back and forth from end to end of the mould.
6. Leave it to cool room temperature for 30 to 40 minutes and then place it in water bath maintained at a specific temperature for 30 minutes.
7. Cut off excess bitumen by means of hot straight edged putty knife level full.
8. Place the brass plate and mould with briquette specimen, in the water-bath and keep at the specified temperature for about 85 to 95 minutes
9. Remove the briquette from the plate, detach sidepieces and test the briquette immediately.
10. While the test is being conducted, make sure that the water in the tank of the testing machine covers the specimen above by at least 25mm and is maintained continuously with in +0.50 C of specified temperature.
11. Attach rings at each end of the clips to the hooks in the testing machine and pull the two clips apart horizontally at a uniform speed as specified until the briquette ruptures.
12. Measure the distance in centimeters through which the clips have been pulled to produce rupture.
13. At least three determinations shall be made for each test.

Figure 3.9 Mould for ductility

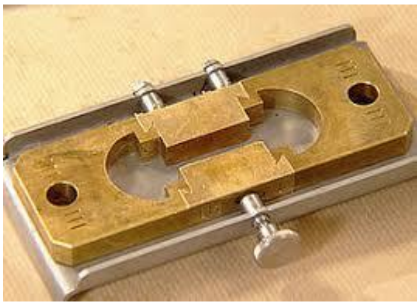


Figure 3.10 Testing machine

3.5 MIXTURE TESTING

3.5.1 Cantabro Test

This test is primarily used for OGFC mixes

Procedures:

1. The test specimen is placed in the Los Angeles Abrasion machine
2. The Los Angeles machine is rotated for 300 revolutions without steel ball
3. After the 300 revolutions, the loose material is discard off the specimen and weight the test specimen
4. Record and designate the weight

Figure 3.11 Los Angeles Abrasion Machine without steel balls

Figure 3.12 Samples of porous asphalt before and after the test

3.5.2 Marshall Stability and Flow of Bituminous Mixture

This test is to measure the resistance to plastic flow of cylindrical specimens of an asphalt paving mixture loaded on the lateral surface by means of the Marshall Apparatus. This test was the same with Marshall Method.

Procedures:

1. Three specimens is ready according to the standard are immersed in a water bath for 30 minutes or in an oven for 2 hours.
2. The testing heads and guide rods are thoroughly cleaned.
3. A specimen is removed from the water bath or oven then placed in the lower jaw and the upper jaw placed in position.
4. The complete assembly is the placed in the compression testing machine and the flow meter adjusted to zero.

Figure 3.13 Sample of Porous Asphalt

Figure 3.14 Marshall Stability Machine

3.5.3 Resilient Modulus Test

Apparatus:

i. Testing machine
ii. Loading device
iii. Loading strips

Procedure:

1. Specimens were kept in the UTM machine at the temperature of 25^{o}C for 15 minutes before start the test.
2. A direct compressive load is to be applied through a 12mm wide loading strips along the vertical diameter of the specimens.
3. Sampled was placed and the loading strip was adjusted to be parallel and centered on the vertical diametral plane. The horizontal strain detector was adjusted to ensure it is in well positioned.
4. 1000N haversine load was applied repeatedly and subjected to 5 pulses. Each sample was tested for 0 and 90 rotation.
5. The average value was taken as resilient modulus value.
6. Repeats steps using different sample incorporating steel fiber

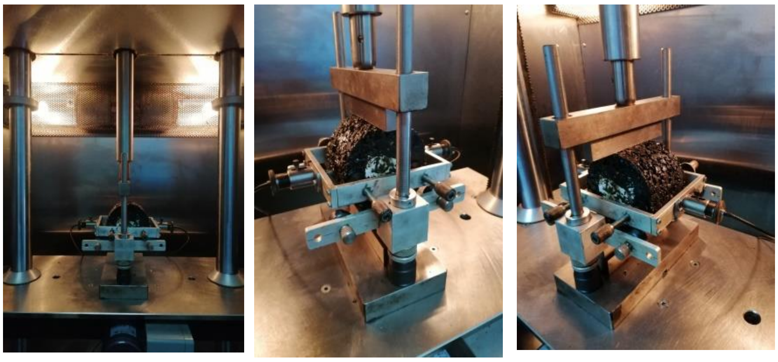


Figure 3.15 Resilient Modulus Test

Figure 3.16 Universal Testing Machine (UTM)

3.5.4 Dynamic Creep

The dynamic creep test was performed using Universal Testing Machine (UTM). It is the most commonly used device to measure the permanent deformation of asphalt mixture in laboratory. Specimen will be placed in the temperature controlled cabinet for 15 minutes to ensure that equilibrium temperature is reached. Specimen was then placed between the platens. The assembled platens and specimen were aligned concentrically with the loading axis of the testing machine. The displacement measuring device is then attached to the platens. The vertical deformation is then measured by the linear variable differential transducers (LVDTs). In this study, the loading parameters consisted of a haversine wave shape and tested in the temperature of 25°C. The specimen was terminated after 3600 load cycles with taken about 2 hours for each samples.The accumulated strain was calculated by using the following equation.

Figure 3.17 Dynamic Creep Test

Figure 3.18 Universal Testing Machine (UTM)

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, the results of the test that had been carried out would be discussed based on the laboratory work. The tests included the results for aggregate tests, bitumen test and performance tests. Aggregate tests included sieve analysis, Los Angeles abrasion test, aggregate impact value test (AIV) and aggregate crushing value test (ACV). Before carried out the performance tests, the samples had been ready for porous asphalt grading B incorporating steel fiber from 0% fiber content to 0.6%. 0% is known as control sample while 0.2% to 0.6% is a modified sample. The asphalt binder used was 60/70 PEN for the bitumen test and also mix it with an aggregate to produce samples. For performance test, the result would be compared between control samples and modified porous asphalt samples so that we can identify the best performance of the fiber content. Last but not least, ranking method had been used to determine the optimum fiber content of the porous asphalt mixtures.

4.2 RESULTS FOR AGGREGATE

4.2.1 Sieve Analysis

The total weight of the aggregates is 1100g including 2% of Ordinary Portland Cement (OPC) as mineral filler. Table below shows the gradation limits of combined aggregates for porous asphalt grading B.

Table 4.1 Gradation limits of Porous Asphalt

SIEVE SIZE (mm)	PASSING (%)	RETAINED (%)	RETAINED (g)
20	100	0	0
14	85 – 1OO	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
TOTAL			1100

4.2.2 Los Angeles Abrasion Test

From the table shows, we get the value of abrasion loss is 21.18% which is less than the requirement of JKR (JKR/SPJ/2008) that shall be not more than 25%. The lower value of abrasion loss, the more resistance to abrasion indicate that is so more tough aggregate From the result we can conclude that the aggregate been used are medium tough because the value of abrasion loss that we get is more than a half of JKR requirement. Road of aggregates should be hard enough to resist abrasion.

Table 4.2 results of LA Abrasion Test

Sample	**Aggregate size (mm)**	**Weight of Crushed Aggregate (g)**			**% Loss**
		Before (M1)	**After (M2)**	**Loss (M3)**	
1	20 – 14	5001.4	3941.77	1059.63	21.18
	14 -10				

Calculation

Loss =(weight of sample before, M1) – (weight of sample after, M2)

= 5001.4 – 3941.77

= 1059.63g

Percentage of Loss $= \frac{M1-M2}{M1} \times 100$

$= \frac{1059.63}{5001.4} \times 100$

= 21.18%

4.2.3 Aggregate Impact Value Test

After carried out the test, we can see the aggregates crush into smaller sizes than their original sizes and the value of material passing at 2.36 mm was much smaller than the retained value. The main objective for this test is to determine the impact value of aggregates and show the resistance of aggregates toward sudden impact. The value of AIV is 14.64% which is less than 25% according to the Standard Specification for Roads Works of JKR (JKR/SPJ/2008). Therefore, it is acceptable and we can conclude that aggregates can sustain the load and resistance to impact to be crushed. Based on the aggregate impact value standard classification, the result is in between 10% – 20% which classified as strong and tough aggregates to resist their disintegration due to impact.

Table 4.3 Results for Aggregate Impact Value Test

Sample	Aggregate size (mm)	Weight of Aggregate (g)			% Loss
		Before test (M1)	Retain at 2.36mm sieve (M2)	Passing at 2.36 mm (Loss) (M3)	
A	14-10	293.66	251.6	43	14.64

Calculation

Percentage of Loss(%) $= \frac{M3}{M1} \times 100$

$= \frac{43}{293.66} \times 100$

= 14.64%

Table 4.4 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

4.2.4 Aggregate Crushing Value Test

The value of ACV is 11.96% which is not more than 25% for wearing surfaces as stated on the JKR requirement. If the value of percentage is much higher that means the aggregates will be more crushed into smaller pieces indicated the lower quality of the aggregates. From the result, the aggregates are tough because the value of ACV less than a half of the limit, therefore the aggregates can sustain the compressive load that subjected to it.

Table 4.5 Results for Aggregate Crushing Value Test

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

Calculation

Percentage of Loss(%) $= \frac{M3}{M1} \times 100$

$= \frac{358.83}{3000.24} \times 100$

= 11.96%

4.3 RESULTS FOR BITUMEN

For bitumen test, the asphalt binder used was 60/70 PEN and three laboratory test is carried out which is penetration of bituminous test, softening point test and ductility. Penetration test for 60/70 PEN is to measure the hardness or constancy of bituminous material the penetration value should be lie between 60 and 70. From the table below, it showed that the penetration value is 63.33 and 70 respectively which is acceptable because lies in between required value. therefore the hardness is suitable to use. Next, softening point of bitumen test has been performed and the temperature of bitumen to become soft for the first one is 48.7’C while 50.5’C for the second test. Therefore the average temperature of softening point is 49.6’C which lies between 48’C to 52’C as per requirement of JKR standard. In addition, the ductility test is performed and the value of the elongation was 104cm which is acceptable because the minimum value for elongation is 100 cm according to the JKR specification.

4.3.1 Penetration of Bituminous Materials

Table 4.6 Results for Penetration of Bituminous Materials

NUMBER OF PENETRATION	SAMPLE A	SAMPLE B
1	59	67
2	66.98	75
3	64	68
AVERAGE	63.33	70

Calculation

Penetration sample A $= \frac{P1 + P2 + P3}{3}$

$= \frac{59+66.98+64}{3}$

= 63.33

Penetration sample B $= \frac{P1 + P2 + P3}{3}$

$= \frac{67+75+68}{3}$

= 70

4.3.2 Softening Point of Bitumen

Table 4.7 Results for Softening Point of Bitumen

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)

Average softening value = (48.7 + 50.5) / 2

= 49.6

4.4 RESULTS FOR MIXTURES

4.4.1 Cantabro Test

Approximately 1100g of aggregates including asphalt binder of 60/70 PEN are used in this test as a compacted hot mix asphalt samples. In order to run the test, the sample placed in the Los Angeles Abrasion machine with 300 revolutions without steel ball to identify the abrasion loss.

As shown in Figure, the abrasion loss value for control samples is much higher than modified samples of porous asphalt which is 8.60%, 9.22% and 14.76% for 100 to 300 revolutions respectively. We can see large different between the modified and unmodified samples. The abrasion loss value for modified sample is lesser than control sample as we can see from the Figure. From the graph below, we can conclude that fibre content of 0.60% is much lower from others fibre content, therefore 0.60% fibre content is the effective fiber content for Cantabro test. Besides, the average of loss of mass is less than 15% which is good according to the JKR specification.

Table 4.8 Results for Cantabro Test

PERCENTAGE OF FIBRE CONTENT(%)	NO.SAMPLE	PERCENTAGE OF ABRASION (%)		
		100 REV	200 REV	300 REV
0	1	10.47	5.22	10.01
	2	6.72	13.22	19.50
	AVG	8.60	9.22	14.76
0.2	1	0.97	1.91	3.31
	2	1.87	3.24	4.87
	AVG	1.42	2.57	4.09
0.3	1	0.51	1.40	3.12
	2	1.26	2.58	3.83
	AVG	0.88	1.99	3.47
0.4	1	4.02	6.25	10.16
	2	2.32	5.30	5.18
	AVG	3.17	5.78	7.67
0.5	1	0.44	1.17	2.92
	2	1.66	4.46	7.85
	AVG	1.05	2.82	5.39
0.6	1	1.65	1.96	3.18
	2	1.97	3.07	3.58
	AVG	1.81	2.52	3.38

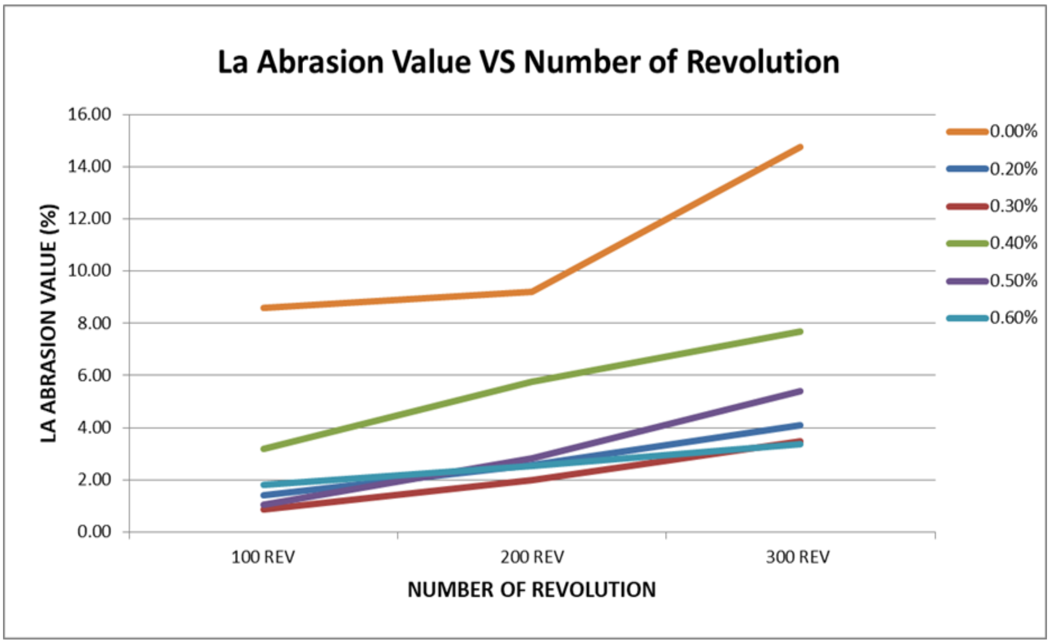


Figure 4.1 Graph of Abrasion value for unmodified and modified samples

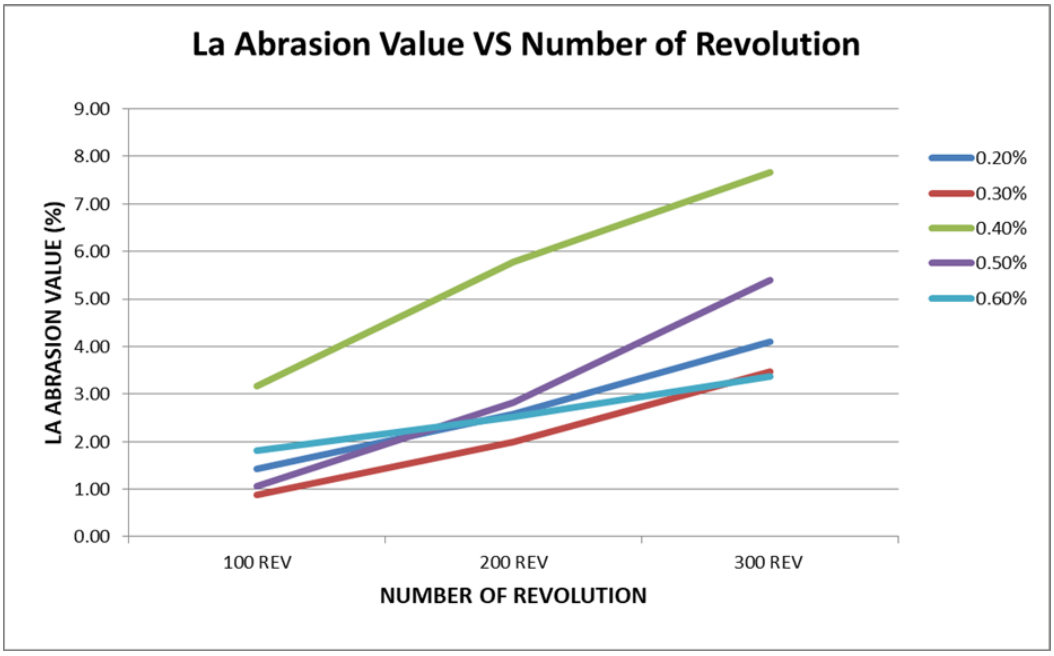


Figure 4.2 Graph of Abrasion value between modified sample

4.4.2 Marshall Stability and Flow Test

From the Marshall Stability and Flow test, 12 porous asphalt samples are used for testing and two values will be recorded directly during the test which is stability and flow value. From the data obtained, we can do a tabulation that contains density, stability, flow, VTM, VFB and stiffness. But for this study, we only use three data as shown on table 4.8 which is stability, stiffness and density value.

As we can see from the figure 4.3, the resistance of stability value to plastic deformation of the mixtures is measured. The highest value of stability is 0.5% of fiber content with 32666.3 N while the lowest value of stability is 4589.1 N. It shows the maximum load which mix can take before deforming to failure. When the mix can take higher load then it will be suitable for heavy traffic load but high flow value is not good because the mix will rut on the pavements.

The density is the analysis on air voids content, VMA, VFA and density of mix. From figure 4.4, the highest number of density value is 0.2% fiber content while the least is 0.5% of fiber content therefore we can determine the most efficient fiber content from the results. Density graph shows the value is decreases with the increase of fiber content. As the fiber content is further increased, the density is reduces while stability and stiffness increase. From previous study stated that fiber will be taking the load leading to a reduction in carrying load capacity. The percentage of improvement for stability is 76%, meanwhile density and stiffness is 89% and 1% respectively.

Table 4.9 Results for Marshall Stability and Flow Test

FIBER CONTENT (%)	STABILITY (N)	STIFFNESS (N/mm)	DENSITY (Kg/m^3)
0	7696.2	1882.87	2.18
0.2	4589.1	454.39	2.21
0.3	11244.2	1082.16	2.19
0.4	4783.5	9315.39	2.20
0.5	32666.3	16670.71	2.10
0.6	12407.1	4702.34	2.13

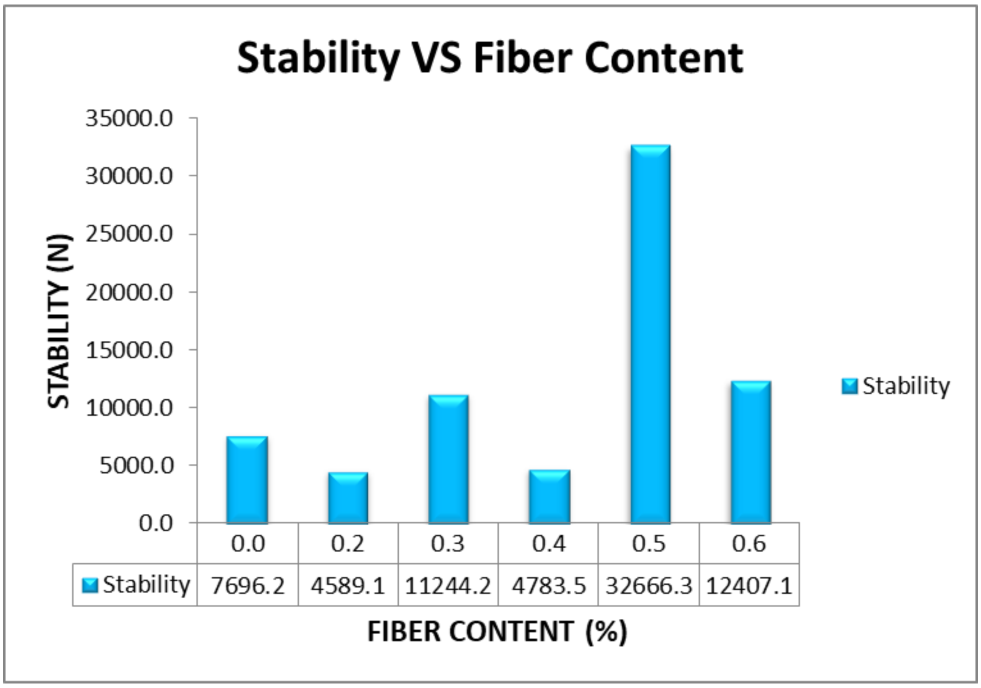


Figure 4.3 Graph of Stability vs Fiber Content

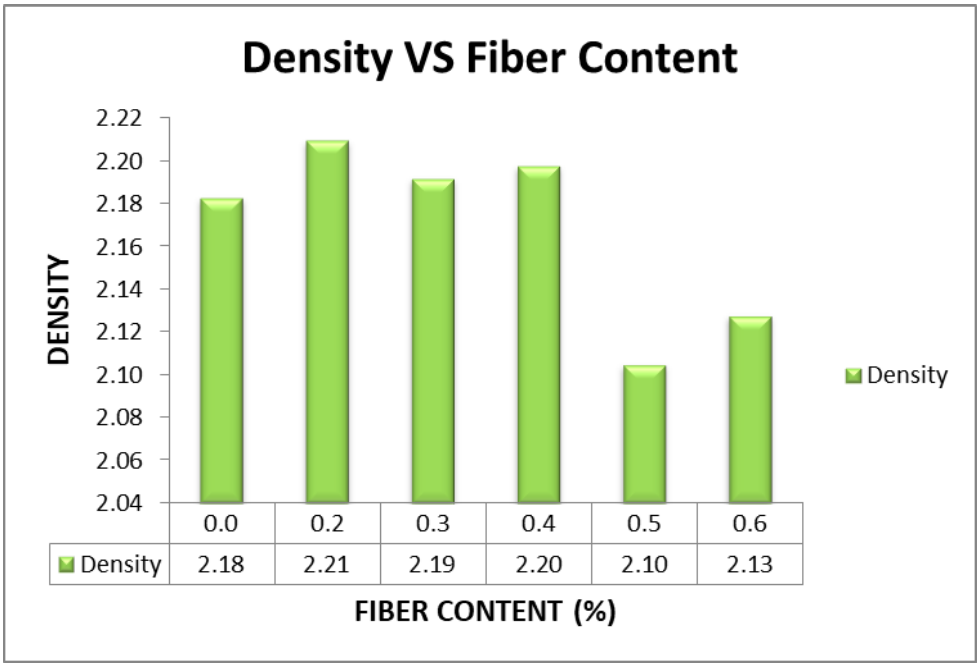


Figure 4.4 Graph of Density vs Fiber Content

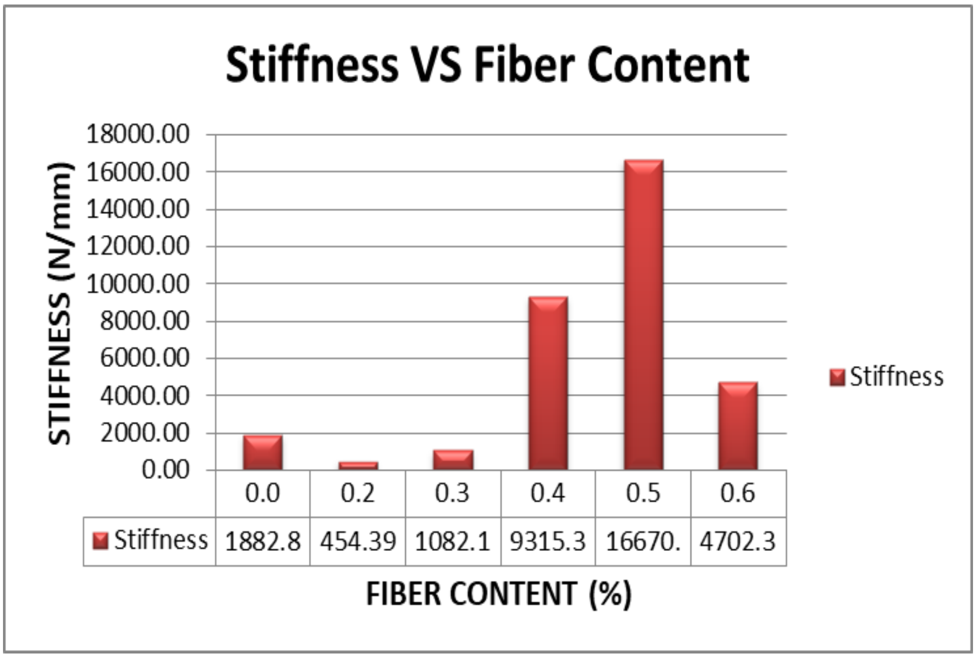


Figure 4.5 Graph of Stiffness vs Fiber Content

4.4.3 Resilient Modulus Test

The resilient modulus test is the test of elastic modulus based on the strain under repeated load which the load is refer to traffic loading. The samples is tested under two different temperature which is 25oC and 40oC and using 1000, 2000 and 3000 pulse repetition respectively. The table and figure above shows the results that we obtained during the tests. The data collection for this test was recorded during the test is shown on table 4.9 qnd 4.10.As we can observed the resilient modulus for porous asphalt modified sample was higher than unmodified porous asphalt. It indicates the increases of stiffness of samples when fibers are added, which could have greater performance of asphalt pavements to withstand rutting. Based on the results for resilient modulus we can see the result in temperature 25'C is more efficient and higher for modified porous asphalt than test results at temperature 40'C. From figure 4.6 and 4.7, the number percentage of fibre content with highest resilient modulus is 0.5% at temperature 25OC while 0.6% for temperature 40oC. We can observe that modified sample has higher elasticity modulus at both temperatures. Both figure presents, as the load is applied, the stress increases as does the strain. When the stress is reduced, the strain also reduces but all of the strain is not recovered after the stress is removed.

Table 4.10 Result for Resilient Modulus Test at 25'C

	STEEL FIBER CONTENT (%)	AVERAGE OF RESILIENT MODULUS (Mpa)		
		1000	***2000***	***3000***
AT 25'C	0	894.5	896.5	953
	0.2	1787	1800	1892.5
	0.3	898	733.5	660
	0.4	1661.5	1423.5	1474
	0.5	1890.5	1482.5	1627
	0.6	1125	1171.5	1165

Table 4.11 Result for Resilient Modulus Test at 40'C

	STEEL FIBER CONTENT (%)	AVERAGE OF RESILIENT MODULUS (Mpa)		
		1000	***2000***	***3000***
AT 40'C	0	655	633.5	613
	0.2	1037.5	903	800
	0.3	869	772	687.5
	0.4	866.5	825.5	805.5
	0.5	1183.5	1073	989.5
	0.6	1465	1345.5	1314

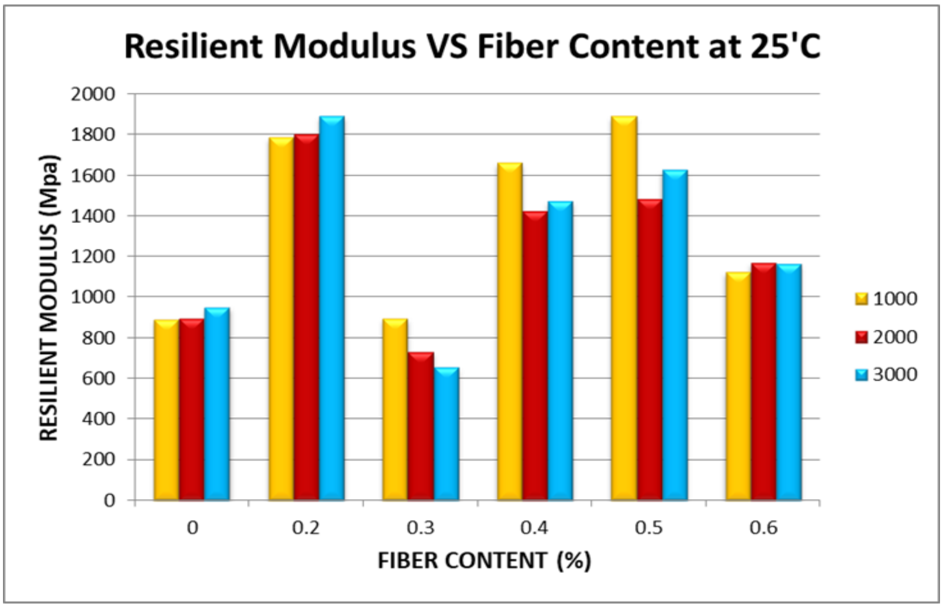


Figure 4.6 Graph of Resilient Modulus at 25'C

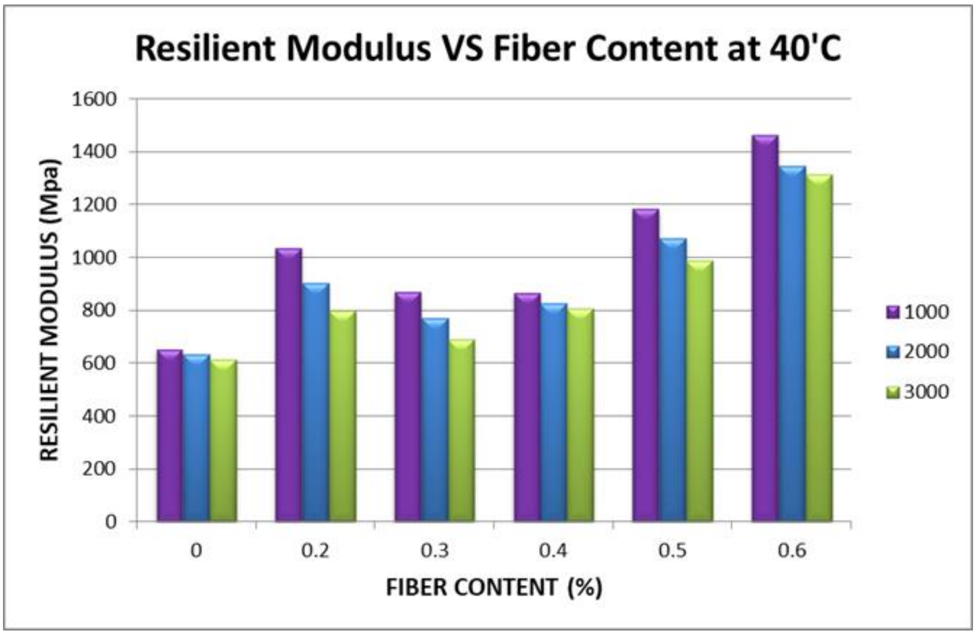


Figure 4.7 Graph of Resilient Modulus at 40’C

4.4.4 Dynamic Creep Test

After testing, the dynamic creep curves and the value of strain is obtained. From figure 4.8 presents the comparison of strain value between modified and unmodified samples As we can see there are significant different among the curves between the fiber contents. Different fiber content produces different number of strain. From the curve, it shows two stage of the curve which is the primary and secondary stage. In primary stage, it presents the elastic strain of the mixture while secondary stage show viscoelastic strain by axial stress. There is also tertiary stage but it does not occur for my samples and usually in this stage it shows that the sample has an internal cracking within the material and considered fail.

Higher axial strains values indicate that mixes have lower rutting resistance as can be seen in the figure. Results show that the strain for steel fiber modified porous asphalt is improves compared to the control mixtures. It implies that by incorporating steel fiber provides impact on susceptibility mixtures to permanent deformation. Katman, H.Y, and et a l (2015) described that the ultimate strain increase at higher temperature. Therefore the samples will be deform faster as stress increase also caused a dramatic growth so this samples will faced a total destruction.

From the table 4.11, the lowest value of strain is 0.3% fiber content with 5191.76 while the higher value is 0.4% with 10411.9 strain respectively. The percentage of improvement for dynamic creep is 31%. For this graph the lowest value of strain is better than highest. Therefore, this modified mixtures capable in improving the performance of the porous asphalt.

Table 4.12 Results of Strain for Dynamic creep test

STEEL FIBER CONTENT (%)	STRAIN
0	6803.98
0.2	6828.41
0.3	5191.76
0.4	10411.9
0.5	9154.83
0.6	7661.29

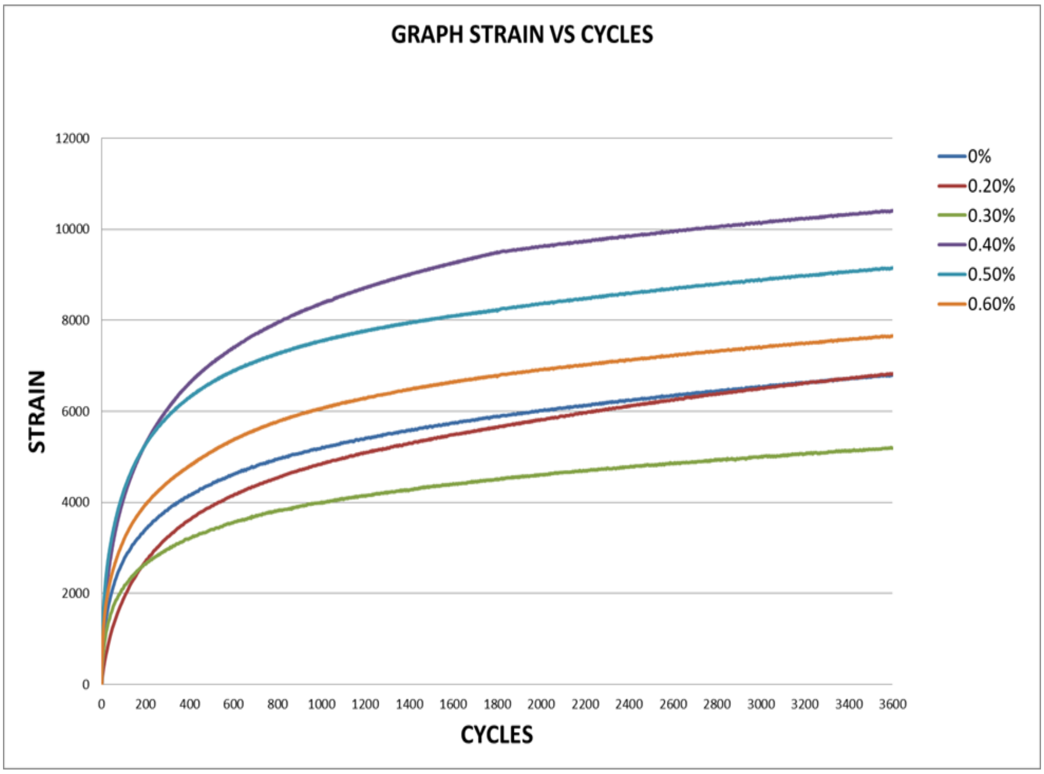


Figure 4.8 Graph of Strain vs Cycle

4.4.5 Determination of Optimum Fiber Content

To determine the optimum fiber content, a ranking method is used. The number in the figure 4.9 presents the number of the ranking performance of the fiber content on each test. Number 1 is the highest and good performance while number 6 presents the lowest and bad performance of fiber contents. Lastly, the total number is calculated and the highest number of total value would present the optimum fiber content for porous asphalt mixtures. As shown in the figure, 0.6% fiber content has the lowest total value which represents the optimum fiber content while 0% fiber content is the highest total value which presents the worst performance.

Table 4.12 Ranking for Optimum Fiber Content Determination

	0 %	**0.2 %**	**0.3 %**	**0.4 %**	**0.5 %**	**0.6 %**
LA ABRASION	6	3	2	5	4	1
DENSITY	4	1	3	2	6	5
STABILITY	4	6	3	5	1	2
STIFFNESS	4	6	5	2	1	3
RESILIENT MODULUS AT 25C	5	1	6	3	2	4
RESILIENT MODULUS AT 40C	6	3	5	4	2	1
DYNAMIC CREEP	3	2	1	6	5	4
TOTAL	32	22	25	27	21	20

CHAPTER 5

CONCLUSION

5.1 Introduction

This study experimentally investigated the performance of porous asphalt incorporating steel fiber with different percentage of fiber content on abrasion resistance, stability and flow, resilient modulus and dynamic creep. Based on the results, the following conclusions can be drawn:

1. Results indicated that fiber can effectively recover the abrasion resistance of asphalt.
2. With the addition of steel fiber in porous asphalt mix, the Marshall stability increases up to 76% higher stability respectively
3. With the addition of steel fiber in porous asphalt, the average resilient modulus increases up to 50% respectively at temperature of 25^{o}C whereas the increases in resilient modulus is up to 55% respectively at temperature of 40^{o}C.
4. For dynamic creep test, it shows that the modified porous asphalt has the best result.
5. Total ranking of the sample for modified and unmodified porous asphalt through all the performance tests indicates 0.6% is the best ranking among all the fiber contents while 0% is the low ranking.

5.2 Recommendation

1. Analyze the effect of various steel fiber length towards porous asphalt performance
2. Appropriate design procedure for porous asphalt mixture that will render the satisfactory performance of PA during service.
3. Comparison study of moisture damage tests methods for evaluating anti-stripping treatments in porous asphalt mixtures.
4. Estimation of permanent deformation in asphalt concrete layers due to repeated traffic loading
5. Effects of transverse distribution of heavy vehicles on thickness design of full-depth asphalt pavements
6. Evaluation of physical and fractional properties of asphalt and their interrelationship

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APPENDIX A
SAMPLE FOR CANTABRO TEST

% OF FIBRE CONTENT	NO.SAMPLE	BEFORE	AFTER			% OF ABRASION		
			100 REV	200 REV	300 REV	100 REV	200 REV	300 REV
0	1	1133.12	1014.46	1073.95	1019.70	10.47	5.22	10.01
	2	1111.66	1036.94	964.67	894.87	6.72	13.22	19.50
	AVG	**1122.39**	**1025.70**	**1019.31**	**957.29**	**8.60**	**9.22**	**14.76**
0.2	1	1178.87	1167.39	1156.39	1139.80	0.97	1.91	3.31
	2	1106.16	1085.50	1070.35	1052.32	1.87	3.24	4.87
	AVG	**1142.52**	**1126.45**	**1113.37**	**1096.06**	**1.42**	**2.57**	**4.09**
0.3	1	1160.44	1154.51	1144.20	1124.25	0.51	1.40	3.12
	2	1114.36	1100.37	1085.63	1071.72	1.26	2.58	3.83
	AVG	**1137.40**	**1127.44**	**1114.92**	**1097.99**	**0.88**	**1.99**	**3.47**
0.4	1	1166.85	1119.94	1093.89	1048.32	4.02	6.25	10.16
	2	1176.61	1149.30	1127.40	1115.68	2.32	5.30	5.18
	AVG	**1171.73**	**1134.62**	**1110.65**	**1082.00**	**3.17**	**5.78**	**7.67**
0.5	1	1171.87	1166.66	1158.14	1137.60	0.44	1.17	2.92
	2	1161.59	1142.28	1109.79	1070.37	1.66	4.46	7.85
	AVG	**1166.73**	**1154.47**	**1133.97**	**1103.99**	**1.05**	**2.82**	**5.39**
0.6	1	1162.35	1143.17	1139.53	1125.36	1.65	1.96	3.18
	2	1155.04	1132.30	1119.54	1113.72	1.97	3.07	3.58
	AVG	**1158.70**	**1137.74**	**1129.54**	**1119.54**	**1.81**	**2.52**	**3.38**

APPENDIX B
SAMPLE MARSHALL STABILITY & FLOW TEST

					SG_{eff}			=	2.6		SG_{app}	=	2.7		**Volume**	**Corr**	1.0	9.80665
TYPE OF MIX : POROUS ASPHALT					SG Bitumen			=	1.03						509-522	1.00		
BITUMEN : 60/70					SGBlended			=	2.6						523-535	0.96		
															536-546	0.93		

Sample No	% Bitumen Content	Weight(gram)			Bulk Volume cc.	Specific Gravity		Volume - % Total			Voids (%)			Stability (N)			Flow (mm)	Stiffness (N/mm)
		In Air	In Water	SSD		Bulk	TMD	Bitumen	Aggregate	Voids	VMA	VFA	VTM		Measured	Corr. Stability		
a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s
					e-d	c / f		b x g / SGbit	(100-b)×g / SGag	100-i-j	100-j	100(i/l)	100-(100g/h)					
1	0.0	1133.0	637.2	1159.6	522.4	2.169								0.93	8472.0	7879	2.0	3904.3
2		1109.6	629.4	1154.4	505.0	2.197								0.93	8079.0	7513	6.2	1220.3
AVG	**0.0**					**2.183**	**2.587**	**0.0**	**84.4**	**15.6**	**15.6**	**0.0**	**15.6**			**7696**	**4.1**	**1882.9**
1	0.2	1069.7	616.8	1099.2	482.4	2.217								0.93	5224.0	4858	2.1	2292.7
2		1094.2	626.2	1123.1	496.9	2.202								0.93	4645.0	4320	0.0	238.9
AVG	**0.2**					**2.210**	**2.579**	**0.4**	**85.2**	**14.3**	**14.8**	**2.9**	**14.3**			**4589**	**1.1**	**454.4**
1	0.3	1125.2	641.4	1155.3	513.9	2.190								0.93	3851.0	3581	0.6	5767.2
2		1151.8	651.7	1176.6	524.9	2.194								0.93	20330.0	18907	20.2	937.8
AVG	**0.3**					**2.192**	**2.575**	**0.6**	**84.5**	**14.9**	**15.5**	**4.1**	**14.9**			**11244**	**10.4**	**1082.2**
1	0.4	1235.3	694.7	1252.6	557.9	2.214								0.93	6502.0	6047	0.7	8227.0
2		1160.0	654.4	1186.1	531.7	2.182								0.93	3785.0	3520	0.3	12055.0
AVG	**0.4**					**2.198**	**2.571**	**0.9**	**84.6**	**14.5**	**15.4**	**5.6**	**14.5**			**4783**	**0.5**	**9315.4**
1	0.5	1158.7	634.6	1186.5	551.9	2.099								0.93	9808.0	9121	3.6	2499.7
2		1159.3	634.9	1184.2	549.3	2.111								0.93	60442.0	56211	0.3	208189.1
AVG	**0.5**					**2.105**	**2.568**	**1.0**	**81.0**	**18.0**	**19.0**	**5.4**	**18.0**			**32666**	**2.0**	**16670.7**
1	0.6	1175.8	645.3	1201.4	556.1	2.114								0.93	13676.0	12719	1.6	7894.9
2		1175.8	650.9	1199.9	549.0	2.142								0.93	13006.0	12096	3.7	3299.4
AVG	**0.6**					**2.128**	**2.564**	**1.2**	**81.8**	**17.0**	**18.2**	**6.8**	**17.0**			**12407**	**2.6**	**4702.3**

APPENDIX C
SAMPLE FOR RESILIENT MODULUS

	Steel Fibre	0'			90'			AVG		
	content (%)	1000	2000	3000	1000	2000	3000	1000	2000	3000
25'C	0	1010	1011	1110	779	782	796	894.5	896.5	953
	0.2	2362	2428	2603	1212	1172	1182	1787	1800	1892.5
	0.3	668	688	682	1128	779	638	898	733.5	660
	0.4	1068	1021	1005	2255	1826	1943	1661.5	1423.5	1474
	0.5	1051	1521	2049	2730	1444	1205	1890.5	1482.5	1627
	0.6	703	666	586	1547	1677	1744	1125	1171.5	1165

	Steel Fibre	0'			90'			Avg		
	content (%)	1000	2000	3000	1000	2000	3000	1000	2000	3000
40'C	0	889	771	729	421	496	497	655	633.5	613
	0.2	1272	1085	972	803	721	628	1037.5	903	800
	0.3	898	789	732	840	755	643	869	772	687.5
	0.4	848	810	793	885	841	818	866.5	825.5	805.5
	0.5	1224	1079	948	1143	1067	1031	1183.5	1073	989.5
	0.6	1768	1648	1611	1162	1043	1017	1465	1345.5	1314