PERFORMANCE OF STONE MASTIC ASPHALT INCORPORATING STEEL FIBER.

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ABSTRAK

Batu Mastic Asfalt (SMA) adalah jurang campuran campuran gred panas yang mengandungi peratusan besar agregat dan pengisi bitumen mastic. Biasanya campuran SMA telah ditambah dengan pengikat polimer yang diubah suai. SMA menderita pengaliran parah yang teruk akibat jurang campuran agregat yang bergred yang cenderung memberikan batu yang stabil ke batu batu termasuk campuran kaya mastic asfalt. Serat Keluli adalah bahan tambah yang akan menstabilkan mortar asfalt dan menebalkan bitumen untuk mengelakkan pengikat berlebihan. SMA baik untuk digunakan dengan kehadiran serat untuk meningkatkan ketahanan campuran SMA. Oleh itu, kertas ini membentangkan keberkesanan menggunakan gentian keluli dalam meningkatkan daya tahan di lapisan permukaan turapan SMAadalah lapisan yang secara langsung terdedah kepada kesan lalu lintas. Untuk membuat campuran SMA, spesimen dipadatkan dengan menggunakan 50 pukulan pada setiap muka menggunakan pemadat Marshall pada suhu pemadatan tertentu. Kemudian, spesimen yang telah diubah suai telah diuji untuk menilai prestasi dari segi ujian Los Angeles Abrasion, Ujian Kestabilan Marshall, Ujian resilient Modulus dan Dynamic Creep. Keputusan menunjukkan bahawa spesimen yang mengandungi gentian keluli boleh digunakan dalam kursus pengikat jalan kaki yang fleksibel kerana kesan kestabilan yang positif. Hasilnya menunjukkan bahawa penambahan gentian 0.3% membawa kepada kestabilan dan kekukuhan yang lebih baik sementara, penambahan gantian 0.5% untuk dinamik modulus berdaya tahan meningkat pada 25 ℃ dan penambahan 0.4% pada 40 ℃. Kesimpulannya, penambahan serat keluli dalam campuran mempunyai potensi untuk memperbaiki masalah pengikat. menjana campuran turapan yang lebih baik, disarankan untuk membuat kajian lanjut pada masa akan dating menggunakan serat pada suhu yang dipadatkan dan jumlah pukulan yang berlainan.

ABSTRACT

Stone Mastic Asphalt (SMA) is a gap graded hot mix asphalt that contains a large percentage of course aggregate and bitumen filler mastic. Usually, SMA mixes has been added with polymer modified binder. SMA is suffer with severe binder drain down due to the gap graded aggregates mixtures that tends to provide a stable stone to stone skeleton including a rich mixture of asphalt mastic. The Steel Fiber is the additive that will stabilize the asphalt mortar and thicken the bitumen to prevent excessive binder drain down. SMA is good to be used in the presence of fiber to enhance the durability of the SMA mixes. Thus, this paper is presenting the effectiveness of using steel fiber in improving the durability at the surface layer of SMA pavement, which are directly subjected to the traffic effects. To prepare SMA mixtures, Specimens were compacted by applying 50 blows on each face using a Marshall Impact compactor at specific compaction temperatures. Then, the modified specimens were tested to investigate the performance in terms of Los Angeles Abrasion Test, Marshall Stability Test, Resillient Modulus Test and Dynamic Creep. The results indicated that the specimens incorporating steel fiber can be used in binder course of flexible pavement because of its positive stability impact. The result shows that the addition of 0.3% fiber lead to better stability and stiffness while, 0.5% fiber for resilient and enhanced modulus dynamic creep at 25℃ and 0.4% fiber at 40℃. Thus, it can be concluded that the addition of steel fiber in the mixture has the potential to improve binder drain down problem. In order to generate a better pavement mixes in the future, it is advisable to have a further research using the fiber at different compacted temperature and different number of blows.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Pavement is necessary in any country. Pavement can be defined as the most upper surface of the road. Road, runway, street and etc are the best example of the roads pavement that is hard surface. According to other structure in Civil Engineering, pavement is ordinary to be sturdy and durable to withstand the heavy traffic loads. Flexible pavement and rigid pavement are both classified as road pavements (Mohod and Kadam 2016). The rigid pavement is fabricated of Portland cement concrete while the flexible pavement are the mixture of aggregates, bitumen and soil layers. According to (Pereira and Pais 2017), the subgrade, Subbase, base course and the surfacing are the main layers in flexible pavement. Flexible pavement is a mixture of aggregates and bituminous material that is compacted with granular that poured on the top level. In Malaysia flexible pavement are usually used for the roads. Flexible pavement is just like its name "flexible" since the total pavement structure bends and deflects due to its load. In order to accommodate the flexing, It is also normally composed of several layers of materials with flexible surface course. Flexible pavement also plays it function that will distribute imposed loads over the large area of natural soils but smaller area distribution to be compared to rigid pavements.

Hot mixed Asphalt (HMA) is the asphalt aggregate mixture that usually produced at batch mixing facility and must be mixed, spread and laid at an elevated temperature that in range of 140℃ to 160℃ (Kim, Lee et al. 2012). Hot Mixed Asphalt (HMA) is still the process of heating aggregates and asphalt binder.

In general, the asphalt binder is mixed with the aggregate at desired temperature to fully coated aggregate and binder and prepare for suitable for paving. The viscosity will turn out lower at lower temperature and lets the aggregate to be fully coated compared to what is conventionally required in HMA production (Kilas, Vaitkus et al.

2010). These will contribute to the combined weakening of the mastic and weakening of the aggregate-mastic bond.

In order to improve the performance of asphalt mixtures, the using of using fiber is not new in industries. It is continuously being introduced in industries as a new fiber materials such as steel fiber, carbon fiber, cellulose fiber, kenaf fiber, bamboo fiber, etc. Steel fiber were added to enhance the performance of the stone mastic asphalt. According to (Akbulut, Woodside et al. 2000), Fibers such as cellulose, mineral and polyester fibers in the mixture were used to stabilize the mastic asphalt and reduces binder drain down especially for stone mastic asphalt or open graded friction course during the material transportation and paving (Hassan, Al-Oraimi et al. 2005).

1.2 Problem Statement

In this new era technologies, fibers has been used widely in stone mastic asphalt (SMA). Stone Mastic Asphalt was designated to be a hot mixture asphalt with high content of course aggregate, high binder content mortar and fibers additive (Arshad, Masri et al. 2017). According to JKR/SPJ/2008 stone mastic asphalt comprises 65% of course aggregate to meet the requirement before used in Malaysia. The origin purpose of using stone mastic asphalt is that it can improved rutting resistant and resist studded tyre wear(Mahrez and Karim 2010). Besides that, factors such as heavy traffic loads tends to effect the performance of SMA because SMA always shown to give better resistance to plastic deformation and good low temperature properties. SMA is categorized by gap-graded in term of aggregate gradation and high content of course aggregate. Thus, the asphalt concrete facing a binder drain down problem due to its aggregate gradation that caused by the high content of course aggregate (Ahmedzade and Sengoz 2009). A common method to solve this problem was by modifying the asphalt mixtures by adding Steel Fiber. Since Steel Fiber was an additives that tends to stabilize improvement of the properties for civil engineering materials, this study intends to promote Steel Fiber as an additive in asphalt mixture in order stabilize the asphalt mixture and reducing the binder drain down. Thus, the mixtures ensure the homogeneity of the asphalt mixture.

1.3 Objectives

The aim of this study is to enhance the performance of Stone Mastic Asphalt (SMA) with the existence of Steel Fiber. Among the objectives are:

a) To determine the materials properties of PEN (60-70) of asphalt binder and aggregate SMA20.

b) To determine the optimum Steel Fiber content for Stone Mastic Asphalt 20 by evaluating the performance test.

c) To evaluate the mechanical performance of Stone Mastic Asphalt 20 incorporating Steel Fiber.

1.4 Scope of Study

This study focuses to perform a laboratory study to evaluate the performance of stone mastic asphalt incorporating steel fibers. This research undergoes laboratory testing on the material properties test of asphalt binder and aggregate. First and foremost, for the aggregates, it undergoes sieve analysis test, Los Angeles Abrasion Value Test, Aggregate Impact Value Test, Aggregate Crushing Value Test, Flakiness and Elongation test. The testing for the asphalt binder were the physical properties test such as penetration test at 25°C, softening point test and ductility test. By using the results from the physical properties test, the Penetration Index (PI) and the temperature susceptibility of asphalt binders can be determine using nomograph of PI(SP/pen). Marshall Mix Design test also was done in order to find the value of Optimum Bitumen Content.

50 mixture identical specimens were prepared. The steel fiber will be mix with the virgin bitumen 60/70 penetration grade for the whole specimen preparations. 50

samples of asphalt mixtures were prepared by using 0%,0.2%,0.3%,0.4%,0.5% and 0.6% steel fiber content. Specimens were compacted by applying 50 blows on each face using a Marshall Impact compactor at specific compaction temperatures. Then, the modified specimens were tested to investigate the performance in terms of Los Angeles Abrasion Test, Marshall Stability Test, Resillient Modulus Test and Dynamic Creep.

The specification that were used for this study is inaccordance to Malaysian Public Work Department for Roadworks (JKRSPJ2008).

1.5 Significant of Study

Steel fiber has been used in this research as an additive in the mixture in order to evaluate the performance of stone mastic asphalt. Stone mastic asphalt that was high content of course aggregate has made the stone gradation to be gap-graded and promotes to a steady stone to stone skeleton including a rich mixture of asphalt mastic. Thus, SMA is suffer with severe binder drain down due to the gap graded aggregates mixtures. Regarding to this problem, the study by using stone mastic asphalt that will incorporating steel fiber were conducted. The Steel Fiber is the additive that will stabilize the asphalt mortar and thicken the bitumen to prevent excessive binder drain down. SMA is good to be used in the presence of fiber to enhance the durability of the SMA mixes. Moreover, SMA were suitable to be used as it can stand high traffic loads where resistance to plastic deformation is needed. In addition, the addition of steel fiber may improve the pavement resistance since it can stabilize the asphalt mixture and reduce the binder drain down problem. The basic concept where hot mix asphalt is good in compression and bad in tension were based on the basic idea. Thus, the existence of steel fiber that act as the reinforcement may give needed resistance to tensile stresses.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter represented the literature review of this research. First and foremost, the type of pavement has been discussed in this chapter where pavement can be classified into two type, flexible pavement and rigid pavement. Then, type of flexible pavement including dense graded asphalt, porous asphalt, polymer and followed by the type of pavement that has been used in this research, stone mastic asphalt. This research was used steel fiber as an additive. Hence, type of additive that usually used as new technologies was introduced such as nanosilica, sasobit, anti-stripping agent, type of fibers and overview about steel fiber. Lastly, this topic discussed on the performance of stone mastic asphalt incorporating steel fiber.

2.2 Type of Pavement

The road pavement can be classified into two types which is flexible pavement and rigid pavement.

2.2.1 Flexible Pavement

Flexible pavement is the structural layer that consist of subbase, base, binder and wearing course. The traffic loads are transferred grain to grain contact of the aggregate in flexible pavement in layered system concept (Mathew and Krishna Rao 2007). For example, bituminous road are act like flexible sheet since it lack of flexural strength (Dewangan, Gupta et al. 2013).

Figure 2. 1 Flexible Pavement Layers

The bound that layers within the pavements are such as wearing course, intermediate course and binder course. The most top layer of the flexible pavement is the wearing course. The wearing course is the layer that will in contact with the traffic loads and that is important for wearing course to oppose abrasion and avoid from skidding. The binder courses are overlying on the base course where it will support and separating the traffic load and also endure the shear. The Base Course is the layer where this layer plays a major role in supporting and separating the traffic loads (Mohod and Kadam 2016). It is from specified material built up to the essential designed thickness that normally overlying the subbase course. Next, the subbase course is the layer that are built up with specified material to essential designed thickness right after overlaying the subgrade. This layer provide structural support, act as an aid to separate the load before transmitted to subgrade. A subbase course is the layer that is not compulsory to be done. It is depending on the situations of the pavement constructed quality. Last layer is the subgrade. Subgrade is the layer of upmost of the soil. This layer is the natural layer that imported, supporting, receiving the stresses from the subbase course.

The advantages of the flexible pavement are it is flexibility at the stage of construction. It is also easily to be built at low cost type and available at almost all time. Flexible pavements are easy to reopened and patched it again and when it is broken, it is easily to repair frost heave and the settlement.

The disadvantages of the flexible pavement are it is cheap to construct but higher maintenance costs once its broken. Its life span also short when it is heavily used. It can be damaged by oils and certain chemicals and it is weak edges that curbs or any edge devices are required.

2.2.2 Rigid Pavement

Grid pavement transferred the loads directly from the traffic or others to the sub-grade soil by the pavement flexural strength. The pavement itself act like a rigid plate where it is substantially stiffer than the flexible pavement.

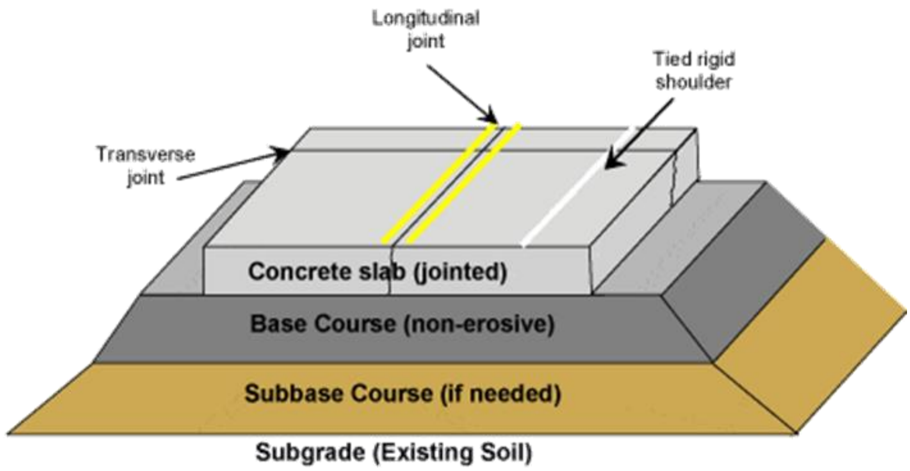


Figure 2. 2 Rigid Pavement layers

It is significantly stiffer than flexible pavements due to Portland Cement Concrete high stiffness become the reason of the term ‘rigid’ pavement. The structure possess certain degree of beam strength that deflects very little under loading due to the high modulus of elasticity of their surface courses. It is noted that, one or more structure layers in a wide are distributed the loads by the pavement’s structure. The function of the portland cement concrete is it will protect weak subbase and base of the layers.

The surface course of rigid pavement is the layer that will in contact with the traffic loads and is made from Portland cement concrete. It has a characteristic such as friction, smoothness, controlling the noisy sounds and drainage. It is functioning as waterproofing layer to the underlying base, subbase and subgrade. The surface course can vary in thickness but it is usually in between specific range. The range for light loading is 150mm or equal to 6inches and for heavy traffic loads is twice of light loading thickness, 300mm or equal to 12inches. The base course is the upper layer of subbase course and beneath the surface course. Its function is providing additional load dispersing, contributes to drainage and frost resistance, uniformly support to the pavement and a platform that stable for construction equipment(Khope and Mohod). This layer also functioning as preventing the subgrade soil movement due to the slam pumping.

The pros of rigid pavement is it is low maintenance cost since rigid pavements have high value as a base for future resurfacing with asphalt. It is also have long life span with thrilling durability. The loads for rigid pavement are distributed over a wide range of area and it tends to reducing the base and subebase requirements.

The cons of the rigid pavements are it is high cost to be construct and the repairing cost also high (Mohod and Kadam 2016). Rigid pavement usually constructed for rough riding quality and it is not recommended for normal usage and joints are compulsory to do for contraction and expansion.

2.2.3 Overview history of roads

Nowadays, road was first built to cross swamp and mountain but now it is built to transports human needs for travelling purpose. The first and legendary one was the world's oldest known paved road that constructed in Egypt. To cut the long story short, the road history started with Romans and then to new Macadam and Telford era and soon after that into the years of flexible and rigid pavement. Metcalf and Telford shared almost the same important elements of road constructions such as the good foundation system and the drainage system. The growth of the pavement design is now used in most of the part on globe. In Malaysia, the pavement design that has been used nowadays needs to have improvement due to some issues like unexpected weather and heavy usage of the roads.

The road pavement is actually the actual surface that is on top of other layers that can be seen by naked eyes or which the vehicles will travel. The function of the pavement is that to provide friction between the tyres of the vehicles and the roads and transferring normal stresses to the underlaying soils.

The most concerning in bituminous pavements is the susceptibility to the moisture damage and it is considered as deprivation of the mechanical possessions of the asphalt.

This is due to the action of the water that will lead to the serious distresses(Singh, Ashish et al. 2017). The loss of cohesion and stiffness of the asphalt, and also the failure of the adhesive bond between the aggregate and asphalt were identified as the main mechanisms of moisture damage in asphalt pavements. The continuing action of moisture induced weakening and traffic load induced mechanical damaged can cause a progressive dislodgement of the aggregate, and is known as stripping of the pavement surface. This will contribute to the combined weakening of the mastic and weakening of the aggregate-mastic bond.

The term bituminous material is applied to any mixture of aggregate and bituminous binder used in road construction. In the United State of America (USA) all aggregate-bitumen mixtures are referred as asphalt, but for the other country, the term that have been used is bitumen. Bitumen is the residue or by-product when the crude petroleum is refined. The materials consist of bitumen which is a black or dark coloured solid. Flexible pavements are constructed with bitumen binder. According to (Walsh 2011), the harder the grade of bitumen used, the stiffer will be the asphalt made from it. The desirable properties of bitumen depend on the mix type and construction.

Asphalt mixtures can be divided into two categories which is hot mix asphalt (HMA) and cold mix asphalt. Hot mix asphalt is being used for the higher volume traffic because the properties of the hot mix asphalt are much better than cold mix asphalt(Akisetty 2008). According to (Mahrez and Karim 2010), the existence of steel fiber in the asphalt mixture was able to enhance the performance of stone mastic asphalt and stabilize the asphalt mortar and offers a better resistance compared to the everlasting deformation.

2.3 Type of Flexible Pavement

2.3.1 Dense Graded Asphalt

Figure 2. 3 Dense graded asphalt

Dense graded mix is also known as well-graded hot mix asphalt proposed for general used. It is relatively permeable when it is properly designed and constructed. This type of asphalt can be further classified as fine graded mixes and course graded mixes.

2.3.2 Porous Asphalt

According to JKR/SPJ/2008-S4, porous asphalt is an extraordinary purpose of wearing course. The production of porous asphalt pavement is using open graded aggregate mixed incorporating with polymer modified binder. This production containing a relatively high and the interconnections of air voids when the compaction is done. An open graded hot mix asphalt mixture is designed to be water permeable. It is used only crushed stone or can be gravel and small percentage of sand that has been manufactured. Porous asphalt pavement has become attractiveness as a storm water best management practice and apply similar mixtures and it must be designed and constructed properly for any porous asphalt mixtures to be used according to (Putman and Kline 2012).

Porous asphalt has been used widely in Europe and other country with wet weather conditions due to its advantages of characteristics. According to (Liu and Cao 2009), porous asphalt has its availability of less splash and spray, low noise, high skid resistance in order to improve driving quality in country with wet weather condition. Unfortunately, porous asphalt is not suitable to be used in hot weather country or overloaded traffics and poor material properties.

2.3.3 Polymer

Polymer can be defined as the performance layers of bituminous pavement in making the life span. Polymer are very costly in industries to be used (Muniandy and Huat 2006). Polymer modified binder is added continuously in the mixture of graded aggregate. The sufficient amount of synthetic fiber is needed incorporating with the mixture in order to produce polymer modified binder. Polymer asphalt is widely used because it can improves the resistance to rutting, resistance towards fatigue cracking, resistance to cracking due to binder hardening and adhesion of binder to aggregates. The performance of the polymer should be following or higher in compliance with AASHTO standard M320-02. Unfortunately, Polymer modified asphalt are poor polymer compatibility which influencing the system in stability, high in viscosity during the processing of the application and high cost to used according (Becker, Mendez et al. 2001)

2.3.4 Stone Mastic Asphalt

Figure 2. 4 Stone Mastic Asphalt

Stone mastic asphalt is a gap graded hot mix asphalt with more that 65% of course aggregates, and according to (Qiu and Lum 2006), optimal asphalt binder for designing aggregate gradation of SMA mixtures are at 5.5 percent. Stone mastic asphalt are the mixing of the aggregates with polymer modified binder. The polymer modified binder in stone mastic asphalt mixing is in between the range of 5.5 to 7.5 percent. Stone mastic asphalt is good in skid resistance since it offers an improvements surface in texture depth where it is in between 0.7 to 1.0mm. The courses aggregate composition are in contact fron point to point forming a skeleton structure tends to provide a great internal friction between the wearing course and the tyres of the vehicles.

2.4 Overview of Stone Mastic Asphalt

In 1970, in order to provide maximum resistance to rutting, stone mastic asphalt was introduced in Germany to avoid the studded tyres on Europe roads. It is proprietary wearing course material that produced in Germany and the performance are following the standardisation in 1984.

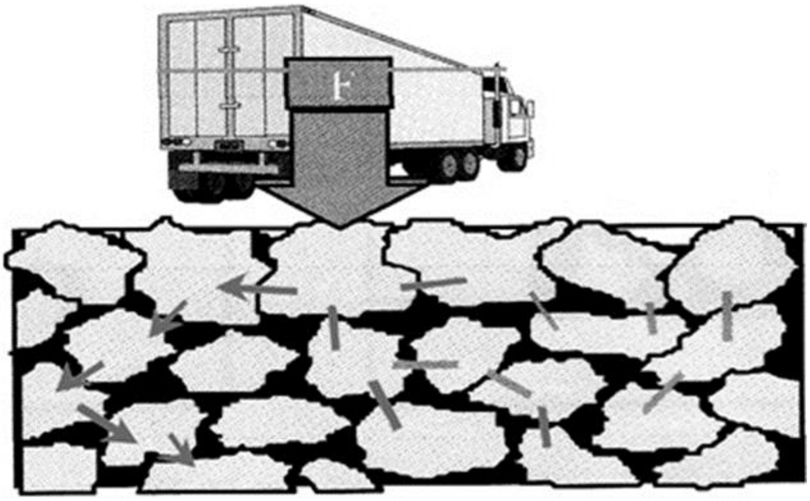


Figure 2. 5 Stone Mastic Asphalt aggregate decomposition

Stone mastic asphalt comprises of course aggregate over 65% and a lot of bitumen filler mastic. SMA is a dense and gap graded hot mix asphalt as shown in figure above. Forming a stone skeleton structure by containing high course aggregate content. The high viscosity in the stone mastic asphalt mixture are filled in the voids performing structural matrix with any stabilising agent like bitumen, crushed sand or filler. The stabilising agent are usually made up of cellulose fiber which prevent binder drainage in stone mastic asphalt mixing. According to (Nunn 1994), stone mastic asphalt have its advantages as it has shown to be very durable surfacing, exhibit high resistance to rutting due to heavy axle loads since its stable aggregate skeleton structure and generates less tyre noise in experienced countries that have adopted stone mastic asphalt. Furthermore, it is reported that stone mastic asphalt has its ability to meet United Kingdom surface texture requirements with a great choice of aggregate size. Stone mastic asphalt are preferable to be used in high loading area such as climbing area or any place that tents to receive excessive loads.

Everything in world has its pros and cons. The cons of the stone mastic asphalt is that, the stone mastic asphalt are not capable to provide permanent solution to diesel spillage problem. Stone mastic asphalt should not be used because of its relatively high cost compared to other asphalt mixing.

2.5 Additive

2.5.1 Nanosilica

Nanosilica is a chemical processed that manufactured from two different sources. The sources of the nanosilica are comes from silica fume and rice husk. Both will give a different result in addition of nanosilica to the modified asphalt binder. It also promises that the nanosilica, the one type of binder modification in the nanotechnology, could give a great improves in binder properties.

In any technologies, there will be some benefit and deficiency. Same goes to nanomaterials in nanotechnology. There are some advantages and disadvantages in using nanosilica in modified asphalt binder.

According to (Yang and Tighe 2013), silica is an ample compound over the earth that is mostly employed in industries to yield silica gel, silica fume and more. The viscosity values will decrease slightly and upgrading the ability in recovering the asphalt binder by adding nanosilica modified asphalt binder. Silica fume and rice husk are the two different sources where the nanosilica was manufactured.

Comparing to other nanomaterial modified asphalt binder, it has to be better performance in resistance to low temperature crack and rutting with addition of 1% of nano powdered rubber VP401. Unfortunately, it is not good in affecting the low temperature properties when the addition of nanosilica into the control asphalt binder and mixtures.

The advantages of nanosilica was found that nanosilica can resist high temperature susceptibility and the asphalt binder could be improved with the addition of nanosilica(Samsudin, Arshad et al. 2016). The result from the researchers of the atomic force microscopy imaging, the addition of nanosilica can improve the surface stiffness.

Nanosilica that is from rice husk has showed the improvement in rotational viscosity at high temperature. Addition of nanosilica in the modified asphalt binder was reported that it can increase the penetration and the temperature of the softening point could be slow down (Ezzat, El-Badawy et al. 2016). A researchers conducted a research of producing nanosilica from rice hush ash at the faculty of Science, Damanhur University,Egypt where the nanosilica has been manufactured.

2.5.2 Sasobit

Sasobit® is one organic or wax additive, produced by Sasol Wax. It is produced from coal gasification using the Fischer-Tropsch (FT) process and is otherwise known as an FT paraffin wax. An "asphalt flow improver" is the term used for sasobit(Hurley and Prowell 2005). Sasobit may lower the viscosity of the asphalt binder during both process, asphalt mixing and lay down operations. It is an aliphatic hydrocarbon produced from coal gasification, which is completely soluble in asphalt binder at temperatures higher than 98°C.The melting point of Sasobit is around 85°C to 115°C. This can reduce working temperature by 15–55°C.

Sasobit has a congealing temperature of about 102°C and is completely soluble in asphalt binder at temperatures higher than (120°C). At temperatures below its melting point, Sasobit reportedly forms a crystalline network structure in the binder that leads to the added stability. Sasol has developed a technology of co-modification of Sasobit plus SBS polymers combined with proprietary cross-linking agent as well as technology for transportable Super Concentrates that enhances the high temperature performance grade (PG) while minimizing the effect on the low temperature PG.

The addition of Sasobit should be engineered to account for affects to the high and low temperature PG. Since 1997, over 142 projects were paved using Sasobit totalling more than 2,716,254 square yards (2,271,499 square meters) of pavement. Projects were constructed in Austria, Belgium, China, Czech Republic, Denmark, France, Germany, Hungary, Italy, Macau, Malaysia, Netherlands, New Zealand, Norway, Russia, Slovenia, South Africa, Sweden, Switzerland, the United Kingdom, and the United States. The projects included a wide range of aggregate types and mix types, including: dense graded mixes, stone mastic asphalt and Gussaphalt. Sasobit addition rates ranged from 0.8 to 4 percent by mass of binder (Hurley and Prowell 2005).

2.5.3 Anti-stripping Agent

Anti-stripping agents are able to improve the adhesion between the asphalt mixture chemically. They are come in the forms of liquid and solid. In order to reduce the moisture susceptibility of Hot Mix Asphalt, hydrated lime usually used as the anti-stripping agent. Portland Cement, Fly-Ash, Flue Dust, etc are the example of other anti-stripping agent while for liquid anti-stripping agent, they usually use liquid Amines and Diamines, Liquid Polymers, etc. (Putman and Kline 2012).

One type of anti-stripping agent is Ordinary Portland Cement. Ordinary Portland Cement is currently defined as a mixture of argillaceous (clay-like) and calcaneus (containing CaCO3 or other insoluble calcium salts) materials mixed with gypsum (CaSO4·2H2O) sintered and then pulverised into a fine powder. A hydraulic cement capable of setting, hardening and remaining stable under water. It consists essentially of hydraulic calcium silicates, usually containing calcium sulphate.

Another type of anti-stripping agent is Pavement Modifier (PMD). The Pavement Modifier is a composed of Calcium Oxide, CaO which mainly came in two forms which are Calcium Carbonate (CaCO3) and Calcium Hydroxide (Ca(OH)2). Other important components are Silica (SiO2) and Magnesium Oxide (MgO), respectively. It is one of the anti-stripping agents which greyish-black powder was appreciably soluble in water that odourless to slight earthy odour. This type of modifier was not flammable and combustible, but when reacted with water might release sufficient heat to ignite combustible materials (Aman and Hamzah 2014).

Other than that, quarry dust and pavement modifier were also used as anti-stripping agent. As reported by Provision & Aggregates (2007), Quarry dust refers namely material below 6 mm from aggregate, sand and gravel production (material below 75 μm). Quarry dust is considered to be deliberately produced to fulfil the grading requirements of specifications. Meanwhile, pavement modifier was a composed of Calcium Oxide.

2.5.4 Steel Fiber

Steel fibers are filaments of wire, deformed and cut to lengths for reinforcement of concrete mortar, cement slurry and other composite materials. Steel fiber is widely used in industries because of its Characteristics. According to (Serin, Morova et al. 2012), The characteristic of steel fiber are such it is not flexible, not fatigue stretching resistance, not shear, resistance to abrasion and etc.

Steel fiber is one of mineral fiber type. Mineral steel fibers was Modified bitumen concrete is the mix of fine and coarse aggregate and the additive mineral steel fibers. According to (Behiry 2013), steel fibers may improve the hardness and the density could be higher. It is observed that the means of strengthening of fibers reinforcement the steel fibers is the mechanism that crack that happened is extending in mineral steel are depends on fracture system. Mineral steel fibers are defined as short discrete with length to diameter from 20 to 100mm. interlocking system in forming a ball will happen if the ratio of the steel fibers is exceeding 100 after shaking thus avoided. And mineral steel fibers with aspect ratio less than 50 are able to disinterlock and can easily be discrete by vibration. Addition of these fibers will increase toughness much more than that first crack strength in these tests (Al-Ridha, HAmeed et al. 2014). Bond due to mineral steel fibers is depending upon aspect ratio.

2.5.5 Kenaff Fiber

Figure 2. 6 Kenaff Fiber

Kenaff fiber is known as Hibiscus Cannabinus that categorize in natural Fiber where it is a local product. It is easily to get because it is a natural product that can be found in Malaysia. It can produce more in tropical according to (Hainin, Idham et al. 2018) and that is non-wood lignocelluloses. (Arshad, Mansor et al. 2016). It is not costly like steel fibers and easily to get because of this product is made in Malaysia. Kenaff Fibers promotes sustainability in pavements since it is an eco-friendly product.

2.6 Overview Steel Fiber

Figure 2. 7 Mineral Steel Fiber

Mineral steel fibers has more advantages as additive in the mixtures of asphalt. It is randomly distribution of steel Leeds to distributed cracking with reduced crack size. First crack tensile strength and ultimate tensile strength of the concrete may be increased the fibers. Shear frictional strength is increased. Addition of mineral steel fibers is not going to decrease amount of shrinkage but it can increase the number of cracks and thus reduce the average crack width. Mineral steel fibers can reliably detain cracking and to improve resistance to weakening as a result of fatigue, impact and shrinkage of pavement. Mineral steel fibers are also effective in supplementing or replacing the stirrups in beams.

2.7 Performance of Stone Mastic Asphalt

Binder drain down are the main causes that are usually inter-related and this causes will leads to the new problems such as stripping or sever binder drain down, rutting, low ride-ability, comfort-ability, motorist safety and last but not least are the general performance (Arshad, Masri et al. 2017). When the bitumens and the aggregates in the mixture flow to the bottom of the mixture and separates itself from the whole mixture is called drain down. Binder drain down happened due to a very high bitumen thickness. In SMA mixtures, the higher the content of binder and filler, the higher the possibility for the bitumen binder to drain off from the mixture.

The internal voids of the uncompacted mix are larger, resulting in more drain down such as Stone Mastic asphalt and porous asphalt (open-graded friction course). Bleeding and drainage are the most Potential problems with SMA.

The difficulty in obtaining the required compaction is the main reason of the storage and placement temperatures cannot be reduced to control this problem. Irregular bitumen distribution due to underflow may result in raveling zones with low bitumen binder content and reduction in permeability in zones with bitumen binder accumulation.

Therefore, to stiffen the stone mastic asphalt, steel fiber as an additive is added because steel fiber are able to increase durability by obtaining higher contents of binder and even at high temperature, the drainage of the mixture may be reduced. In this research, the steel fiber has been used to reduce the binder drain down problem. Thus, the performance of stone mastic asphalt were evaluated in terms of marshall stability test, LA abrasion test, resilient modulus test and dynamic creep test.

CHAPTER 3

METHODOLOGY

3.1 Introduction

To find out the results of the study, there must be an experiment. So, this chapter were discussed on the methodology to evaluate the performance of stone mastic asphalt incorporating with Steel Fiber modified asphalt binder. There were also a discussion on the laboratory testing towards the material that were used in this study such as bitumen, aggregate and stone mastic asphalt. The laboratory testing were conducted at Highway Engineering laboratory, University Malaysia Pahang (UMP). The data were analysed to determine the effect of addition Steel Fiber to the asphalt mixture. The methodology flow chart of this study was shown in figure 3.1.

3.2 Research Framework

Figure 3.1 shows the methodology chart that was used for this research. The research starts from collecting all related information related to this research on the performance of stone mastic asphalt incorporating steel fiber followed by the result and analysis of the data that was compiled in a report documentation.

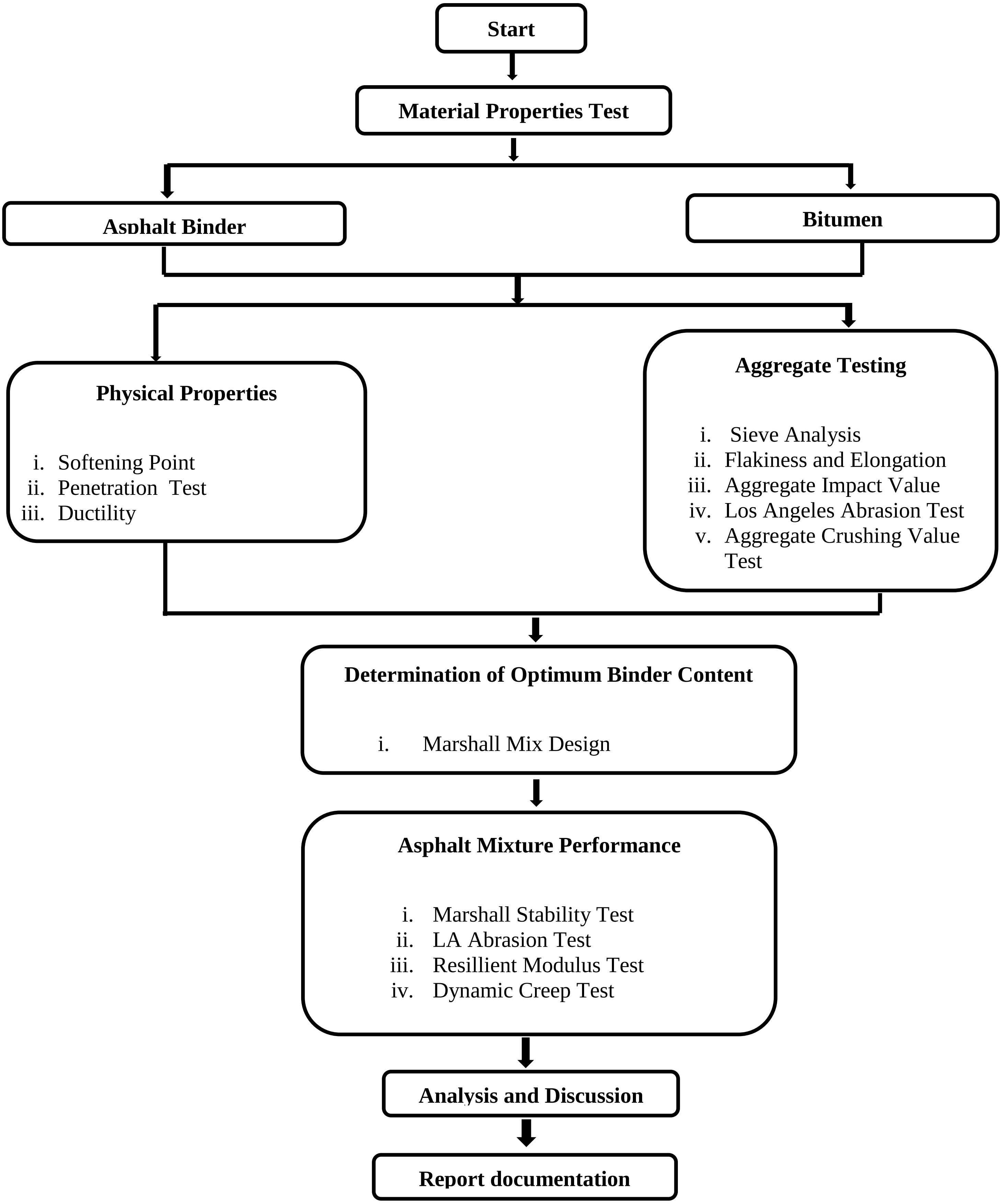


Figure 3. 1 Methodology Flow Chart

3.3 Materials

The material that were used in this study consists of aggregate, asphalt binder, and steel fiber. Aggregates are defined as inert, granular, and inorganic materials that normally consist of stone or stone-like solids. Aggregate can come from either natural or manufactured sources. According to the (Yildirim 2007), the amount of mineral aggregate in asphalt paving mixtures is approximately 95% by weight and at least 85% by volume. The types of the aggregate that were used is granite aggregate. Other material that were used is Asphalt binders. Asphalt binders were most commonly graded by their physical properties. It is a black viscous material. An asphalt binder's physical properties directly describe how it will perform as a constituent in asphalt concrete (AC) pavement. For the production of asphaltic concrete, the binder is normally blended with hot aggregate at a mixing temperature of 160 - 180°C. The bitumen that were used is bitumen penetration grade 60/70. Bitumen is black in colour and is obtained from crude petroleum through a process named filtration process. It is no odour, resistance towards weathering and susceptibility with temperature. It is a material that viscoelastic and this will make the bitumen react as elastic materials depending on loading rate and temperature. Apart from that, Steel Fiber were added to the asphalt mixture in this study. The percentages of steel fiber content that were added in the sample were 0%, 0.2%, 0.3%, 0.4%, 0.5% and 0.6% by weight.

3.4 Binder Properties

The binder used in this research was bitumen with penetration grade 60/70. The test to determine the bitumen quality before put it in the mixture were penetration test, softening point test, and ductility test. The test should meet the JKR/SPJ/2008 requirement before used.

3.4.1 Softening Point Test

Figure 3. 2 Softening Point Test

To determine the softening point of bituminous binder, Softening point test is a method that was used at range of 30℃ to 150℃. The initial bath temperature is 5℃ and thermometer will be used with subdivisions of 0.2℃ in conducting this test. The other intention of this test is to investigate the softness of the bitumen based on the temperature applied to the sample. In accordance to ASTM D36 procedures (ASTM2005c), The ring and ball test were carried out. The two horizontal disk bitumen binders, which are placed in brassed copper rings, are heated at a controlled rate in the liquid bath while each supports steel balls. The softening point is reported as the average temperature in which both disks soft enough to allow each ball, packed in bituminous binder, falling from a distance (25,0 ± 0,4) mm. The differences between the two discs to fall downwards should not exceed 2℃ to the nearest 5℃. For bitumen with penetration 60/70, the range for the disc to fall are in between 49℃ to 56℃.

Procedure of doing softening Point test are:

Figure 3. 3 Bitumen poured in the brass rings

I. Specimen were prepared in precisely sized brass rings and kept at 160°C at the temperature of a hot plate.

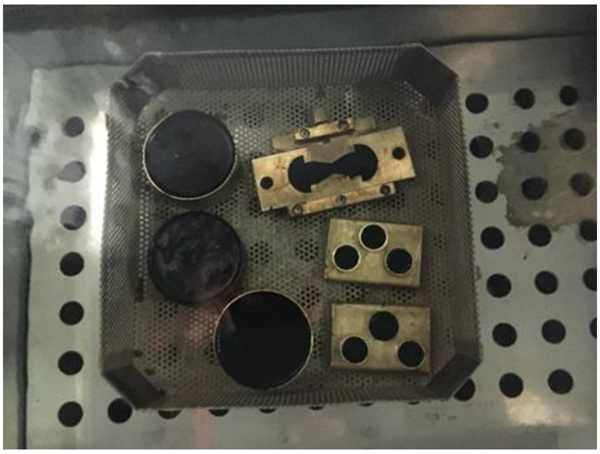


Figure 3. 4 The specimens in water bath.

II. The rings and two ball bearings were placed in a liquid bath filled with distilled water at a depth of 105± 3 mm and kept at a temperature of 5 ± 10°C for 15 minutes.

III. A 9.5mm steel ball bearing weighted approximately 3.5± 0.05g was centred on each specimen and then heat was applied to the beaker to raise the temperature by 5 ± 0.5°C per minute.

Figure 3. 5 Specimen while testing

IV. The result was recorded when the steel ball of each bitumen specimen touches the base plate.

3.4.2 Penetration Test

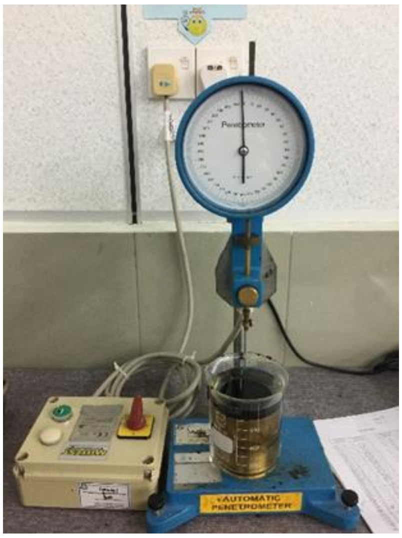


Figure 3. 6 Penetrometer

In order to evaluate the consistency of the bitumen and the suitability of bitumen for use under different temperature conditions and several types of constructions. The penetration of bituminous material is within a tenth of milli meter, that the standard needle will move vertically, be a sample of the material under standard conditions of temperature, load and time. Bitumen should be enough to fill the container to a depth of at least 15mm above the expected penetration. The test was repeated at least for 5 readings in order to obtain the average PV. This test is used for evaluating the consistency of asphalt material before and after heating. The penetration test will be conducted according to ASTM D5 (ASTM 2005b).

3.4.3 Ductility Test

Figure 3. 7 Ductilometer

Ductility test is done to investigate the ductility of the bituminous binder. Ductility of a material is a property by virtual of weight that can be pulled without breaking apart the 'thread'. Bituminous binder used in road should be ductiled such that it can take a deflection that will occur on them when heavy traffic loads hit. Bituminous binder in ductility is a distance that will measured in centi-meters where it will expand before the specimen break it apart when a briquette specimen has been pulled with specific speed and at required temperature. It is tested at a speed of 5 to 100 mm/min. The ductility test will be conducted according to ASTM D113.

3.5 Aggregate Properties

3.5.1 Sieve Analysis Test

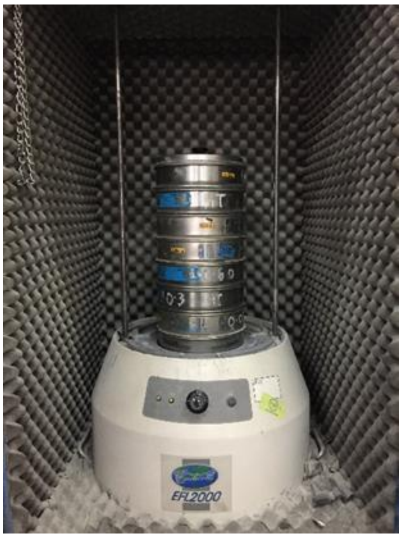


Figure 3. 8 Sieve Analysis Shaker

Sieving is the process of separating aggregate particles by sizes. A sample of dry aggregates that was dried in the oven, are poured onto the top of the sieve and then the machine was until each particle has thrown down to a sieve with passing or the particles that retain. The test was carried out to find the aggregate in term of size as a fine or course aggregates. Course aggregates are defined as a passing sieve size from 37.5mm and retained at 3.35mm while fine aggregate were passing through sieve size 3.35mm and retained at 0.15mm.

3.5.2 Flakiness and Elongation

Figure 3. 9 Flakiness and Elongation Materials

The flakiness and elongation index was conducted accordance with procedures respectively stated in BS 812 : 105.1:1898, (BSI,2000) and BS 812: Part 105.2:1990, (BSI,2000) (Aman and Hamzah 2014).

3.5.3 Aggregate Impact Value Test

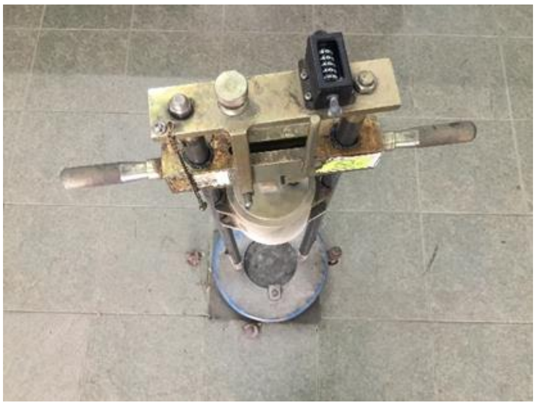


Figure 3. 10 Anggregate Impact Testing Machine

Sturdiness is the property of a material to oppose sway. Because of traffic stacks, the street stones are exposed to the beating activity or sway and there is probability of stones breaking into little pieces. The street stones ought to in this manner be extreme enough to oppose crack under effect. A test intended to assess the sturdiness of stones i.e., the obstruction of the crack under rehashed effects might be called an impact test for pavements.

The AIV provides a relationship measure of an aggregate's resistance to sudden shock or impact, which differs from crushing strength in some aggregates. Each aggregate particle size was weighed in each mixture based on the aggregate gradation ratio. This procedure was followed to meet the requirements for aggregate gradation.

The aggregate sample was prepared by first sieving and the portion that pass the 14.0mm test sieve and retained on 10.0mm was done. It is then washed and dried in the oven for not more than four hours in the range of 100 to 110 degree celcius. It is then cooled to room temperature before running any test. The aggregates that have been cooled is now filled in the steel cylinder with three layers and each layer were tamped for 25 times by using tamping rod. The tamping rod must be free fall down on the aggregates at about 50mm above and it were spread over uniformly. The impact machine is placed with its bottom plate flat on the floor so that the hammer guide columns are vertical. The cup is fixed firmly in position on the base of the machine and the whole of the test sample from the cylindrical measure is transferred to the cup and compacted by tamping with 25 strokes.

The hammer was raised until its lower face is 380mm above the upper surface of the aggregates in the cup, and allowed to fall freely on the aggregates. The test sample was subjected to a total 15 such blows, each being delivered at an interval of not less than one second. The crushed aggregate is then removed from the cup and the whole of it sieved on the 2.36 mm sieve until no further significant amount passes. The fraction passing the sieve is weighed accurate to 0.1gm. The fraction retained on the sieve was weighed and if the total weight of the fractions passing and retained on the sieve was added .It should not be less the original weight of the specimen by more than one gram, if the total weight is less than the original by over one gram the results should be discarded and a fresh test made.

3.5.4 Aggregate Crusing Value Test

Figure 3. 11 Compression Testing Machine

The aggregate crushing value was tested to evaluate the crushing value of the given aggregate sample. The main mechanical properties in operating this test as required in road stones are satisfactory resistance to crushing under the roller during construction. It is sufficient resistance to surface traffic abrasion. Aggregates used in road construction should be strong enough to withstand destruction under the load of the traffic wheels. If the aggregates are weak, the pavement structure's stability is likely to be adversely affected. The strength of course aggregates was assessed by crushing test aggregates. The aggregate crushing value provides a relative measure of crushing resistance under a gradually applied compressive load. To achieve high pavement quality, aggregate with low crushing value should be preferred.

3.5.5 Los Angeles Abrasion Test

Figure 3. 12 Los Angeles Abrasion Machine

Aggregate used on the surface layer of the road pavement are always in contact with the wheel vehicles that moving on it. Friction between moving tires and road surfaces causes aggregate abrasion. This effect is increasing due to the presence of dust particles on the surface of the road. Therefore, the aggregate should have sufficient resistance to abrasion. These features are assessed by abrasion value tests. Another method of determining the abrasion value test is the Deval abrasion test and the Dorry Abrasion Value Test. The Los Abrasion test was used in this study to determine the abrasion value test.

The test sample consists of aggregates passing 12.5 mm sieve and retained on 10 mm sieve and dried in an oven for at least four hours at a temperature of 100 ° C to 110 ° C and cooled to room temperature before testing. Approximately 2.5 kg of materials passing 20 mm sieve and retained on 12.5 mm sieve were taken and 2.5 kg of materials passing 12.5 mm sieve were taken and retained on 10 mm sieve.

LA machine has a hollow steel cylindrical having 70 centimetres of internal diameter and length of 50 centimetres. The machine can be rotate about the origin axis. The steel ball of diameters 48mm and weight between 390-445 grams are needed. The aggregate sample along with the charge (11 steel sphere) are placed in the machine. The machine was rotated about 500 revolutions at 30 to 33rpm according to designation ASTM C131. The sample was removed and it will be sieve on 1.7mm sieve. The fraction passing through sieve will be weight with accuracy of 1gram.

3.6 Determination of Optimum Binder Content

The Marshall Test method is used to determine the optimum binder content (OBC) of hot-mix pavements where stability and durability are required to withstand the action of high-pressure aircraft tires or heavy road traffic. The test was carried out in accordance to the JKR Specification of Road Works (JKR/SPJ/2008)

Three specimens were prepared for each bitumen content within the range of 5% to 7% for the proposed design mixture gradation with increment of 0.5% for SMA20. All specimens were compacted 50 blows according to the standard. The bulk specific gravity for all specimens were determined as soon as the compacted specimens have cooled at room temperature. Stability and flows values of each specimens was obtained in accordance to ASTMD1559. Then, Specific gravity and void analysis was carried out for all the specimen in order to determine the percentage air voids in mineral aggregate and percentage air voids in compacted mix (VIM). The average values of bulk specific gravity, stability, flow, VFB, and VMA obtained was plotted against bitumen content. The tests values were determined at the mean optimum binder content from the plotted graph and it was comply to design standard parameters in JKR Specifications of Road Works. The mean optimum value was determined by averaging the four optimum bitumen contents as follows:

I. Peak of curves taken from stability graph.

II. Flow equals to 3mm from flow graph.

III. Peak curve taken from bulk specific gravity graph.

IV. VIM equals to 3.5% from VIM graph.

3.6.1 Marshall Mix Design

In general, specimens are prepared and compacted following one of two mixture methods depending on the ultimate testing of the sample. If the sample will be used for volumetric property analysis, the sample aggregate mix is adjusted to achieve a desired specimen height following a specified number of gyrations. If specimen air voids are to be controlled, the aggregate mix is adjusted to create a specified density in a known volume. The number of gyrations depends on the design traffic loading for the specimen.

The aggregate mixture associate degreed asphalt binder are heated to a combination temperature vary which will turn out an un-aged binder kinematic viscosity 170±20 mm2 /sec. In general, the compactor operates with a relentless vertical pressure of 600 kPa, associate degreed with an angle of gyration of 1.25 degrees at a gyration rate of 50 rev. The highest and bottom platens of the mould stay parallel throughout the compaction methods, therefore the angle of gyration revolves round the sample. Height of the specimen is mechanically recorded with every gyration, permitting density calculations to be distributed at every height, given mass of the sample. Specimens are either compacted to a specified range of gyrations, or compacted to a specified height for determination of volumetrical or physical properties, severally (Swiertz et. al, 2010).

3.7 Mixture Performance Test

3.7.1 Marshall Stability Test

Figure 3. 13 Marshall Compression Machine

Marshall stability test were somewhat related to evaluate the performance of the asphalt mixture. Tensile strength is related to marshall stability and the low resistance to rutting of the specimen is related to marshall flow (Sengul, Oruc et al. 2013). According to (Chen, Xu et al. 2009), A rate of 50.8mm/min of compressive loading is applied on the specimen In the test until the specimen is broken. The maximum loading at material failure is called Marshall stability (MS), and the associated plastic flow (deformation) of specimen is called flow value (FV).

3.7.2 Los Angeles Abrasion Test

Figure 3. 14 Los Angeles Abrasion Machine Testing

The Cantabro test was used to determine the resistance to abrasion loss. Resistance to abrasion loss via the Cantabro test is typically used to limit the lower binder content of this wearing course (Arrieta and Maquilón 2014). The test is popular on account of its simplicity that is merely by rotating the Marshall sample in a Los Angeles steel drum without steel at 100,200 and 300 revolutions. Its procedure measures the breakdown of compacted specimens utilizing the Los Angeles Abrasion machine. It rotates at a speed of 30–33 rpm for 300 revolutions without steel spheres at 25 °C. After that, the loose material broken off the test specimen must be discarded. The percent of weight loss (Cantabro loss) is an indication of PFC durability and relates to the quantity and quality of the asphalt binder.

3.7.3 Resillient Modulus Test

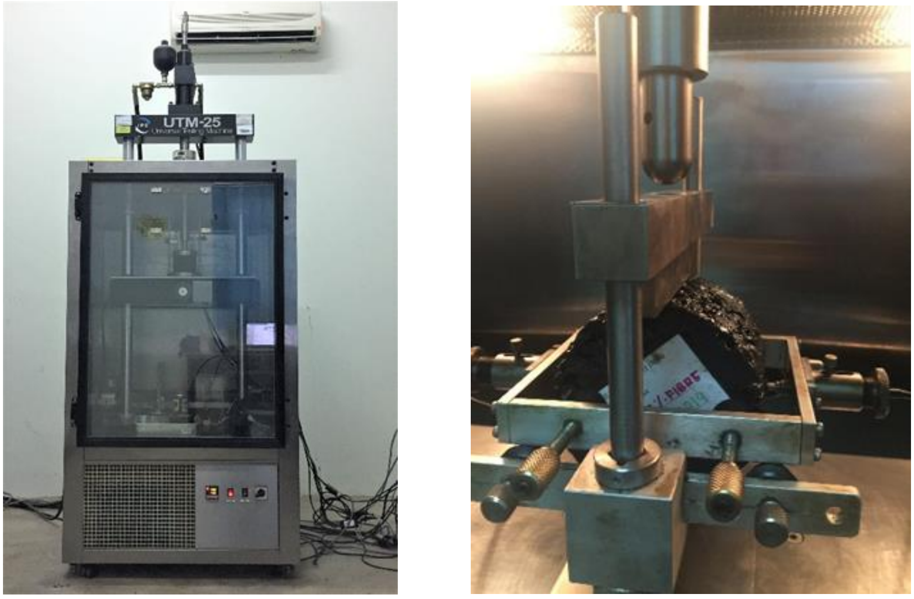


Figure 3. 15 Universal Testing Machine(UTM25) for Resillient Modulus Test

Indirect Tensile Strength Modulus(ITSM) tests were performed to determine the resilient module of asphalt mixtures using a universal testing machine (UTM 25) under the test conditions presented (Karami, Nikraz et al. 2018). The load pulse was applied vertically through a curved loading strip in the vertical diameter of a cylindrical specimen. The resulting horizontal deformation was measured by attaching at each end of the horizontal diameter two linear variable differential transformers (LVDT) at the mid-thickness. Initially, the test specimens were conditioned by applying five load pulses with the specified rise time to the peak load at the specified pulse repetition period, and then the modulus calculation was done based on the average of another five load pulses.

3.7.4 Dynamic Creep Test

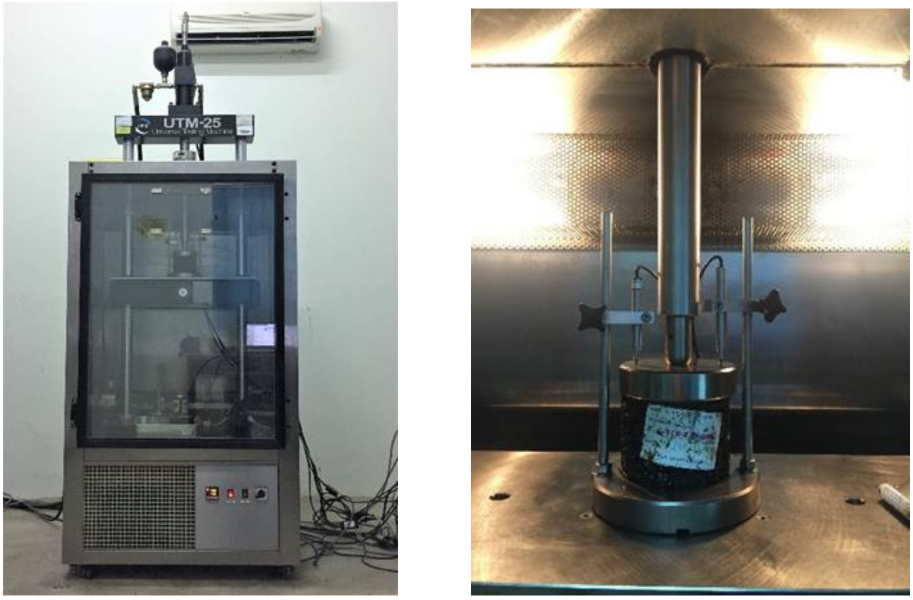


Figure 3. 16 Universal Testing Machine(UTM) for Dynamic Creep Testing

Dynamic creep testing performed using such well-recognized devices as the Universal Testing Machine (UTM), which provides multiple output data with reasonable testing time and less material consumption, seems to be the most popular option for assessing permanent deformation of asphalt mixtures (Katman, Ibrahim et al. 2015). The influence of different temperature and loading conditions (e.g., frequency, duration, load cycles, and stress level) on permanent deformation can be evaluated and incorporated under UTM to match real environmental conditions. Previous research reported that the dynamic creep test had a very good correlation with measured rut depth and a high ability to estimate the rutting potential of asphalt layers. Dynamic creep testing is an appropriate laboratory method to investigate the permanent distortion of modified and unmodified asphalt mixtures. Moreover, the termination of the dynamic creep tests were so closely correlated with the results of the wheel tracking test.

In addition to the laboratory tests, many researchers are interested in developing the performance models to characterize the permanent deformation and further estimate the future pavements' service

Dynamic creep tests were carried out with the following test conditions: terminal pulse count 3600 pulses, conditioning stress 5kPa, test loading stress 100 kPa, preload time 600s, cycle duration 500ms and cycle repetition time 2000ms. The tests were carried out at 25℃ and 40 °C for each of the specimens.

3.8 Analysis and Discussion

All tests had done and all the data had been collected. The analysis stage will be conducted. All the results shown will present the use of Steel Fiber that were affected on the performance of the Asphalt mixture. Thus, the influence of stone mastic asphalt with addition of Steel Fiber in the Asphalt mixture will be analysed using excel, plotting graph and present by table.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The results are analysed to determine the performance of the steel fiber as an additive in the asphalt mixture, whether steel fiber strengthened the hot mix asphalt or not due to heavy loads traffic. The result are obtained from sieve analysis test, flakiness and elongation test, aggregate impact value test, aggregate crushing test, softening point test, penetration test, ductility test, Los Angeles Abrasion test, dynamic creep test, resilient modulus test and Marshall stability test.

4.2 Binder Properties Test

4.2.1 Softening Point Test

Softening point is one of the tests to determine bitumen consistency toward temperature. It was conducted in order to determine at which temperature the bitumen starts to melt. The temperature readings start to be taken when a metal ball that is placed on the bitumen falls to the bottom of the beaker. It is indicated that the bitumen has reached certain degree of softness when the metal ball dropped into the bottom. The average reading of the softening point that had recorded was 53.5 that fall in the range 48 to 56 according to JKR/SPJ/2008 for bitumen 60/70 as shown in the table 4.1 below.

Table 4. 1 Softening Point Test

Sample	Softening Point, R(℃)	Average(℃)
A	53	53.5
B	54	

4.2.2 Penetration Test

Penetration Test is the widely used method of measuring the consistency of a bituminous material at a given temperature. Table 4.2 below show the result for penetration test. The average elongation are in the range 60 dmm to 70 dmm as specified in JKR specifications.

Table 4. 2 Penetration Test

Sample	**Softening Point,R (℃)**			**Average (dmm)**
	1	2	3	
A	60	62	59	60
B	59	61	62	61

4.2.3 Ductility Test

Ductility test is done to determine the ductility of the bituminous binder. Ductility of a material is a property by virtual of weight that can be pulled without breaking apart the ‘thread. The result for ductility test was in the range needed, that is more than 100cm for bitumen 60/70, 110cm. Hence, the bitumen are acceptable to be used for this research.

4.3 Aggregate Test

4.3.1 Sieve Analysis Test

Sieve analysis is the process where aggregate are degrading into the same size. grading or size distribution of the aggregate are the main purpose in order to find out whether the aggregate meet the requirement to be used in the mix or not. Aggregates sizes has been determined by sieve analysis test. The grade for the aggregate used is according to the size of the sieve that follows the JKR Standard Specification for Road Works. From the gradation, the weight use for the aggregate was determined. Aggregates that remained at the 4.75mm sieve size had the highest percentage compared to others. The total weight of the mixture that contained were 1200kg each of the sample. The size of the sieve used were 19.0mm,12.5mm,9.5mm,4.75mm,2.36mm,0.6mm,0.3mm,0.075mm and the pan. The sample included 10%,20%,46%,4%,6%,0.5%,4.5%,7% of aggregates respectively and the mix are including the lime 2%. Table 4.3 below shows the aggregate gradation for SMA20 samples.

Table 4. 3 Gradation Limit for SMA 20

Sieve Size (mm)	**Passing**	**Average**	**Percentage Retain(%)**	**Weight Use (gm)**	**Cummulative of Weight Use (gm)**
19.00	100	100	0	0	0
12.50	90-100	90	10	120	120
9.500	72-83	70	20	240	360
4.750	25-38	24	46	552	912
2.360	16-24	20	4	48	960
0.600	12-16	14	6	72	1032
0.300	12-15	13.5	0.5	6	1038
0.075	8-10	9	4.5	54	1092
Pan	0	0	7	84	1176
Lime	0	0	2	24	1200
Total					

4.3.2 Flakiness and Elongation

Flakiness and elongation test have been done in order to make sure that the aggregates that will be used can gives the high value of strength. The aggregates play the very important roles so that its shape can produce the better interlocking between aggregate and the binder. Based on table 4.4, the result of the flakiness index was 25%. According to JKR specification, the flakiness index value must be less than 25%, so the aggregate was within the predetermined range. For elongation, the decisions resulting from the test shows the value of 24.9%. There was no JKR specification requirement for the elongation. Overall, the value of flakiness and elongation show the positive results in the table 4.4 shown below. Therefore, the aggregates can be used for the research.

Table 4. 4 Flakiness and Elongation Index of Aggregate

Properties	JKR Specification Requirement	Results
Flakiness Index	Less than 25%	25%
Elongation Index	Not stated	24.9%

4.3.3 Aggregate Impact Value Test

Resistance of the aggregates due to the sudden impact can be determined through aggregate impact value test, which the resistance to compressive loadare different to some aggregate. Table 4.5 shows the aggregate impact value result that comparable to the JKR specification. The results show that the aggregate impact value meet the JKR specification.

Table 4. 5 Aggregate Impact Value Test

Sample	Aggregate Size(mm)	Weight of sample before crush (g)	Weight retained 2.36mm sieve (g)	Weight passing 2.36mm (g)	%Loss	JKR Specification
A	10	293.66	251.60	43.00	15	<30%

4.3.4 Aggregate Crushing Value Test

This test is conducted to evaluate the aggregate strength that has been used in the sample can be strong enough to withstand the destruction that comes from the traffic load. Table 4.6 shows the results of the aggregate crushing value that is comparable to the JKR specification. The results show that the crushing value of the aggregate conforms to the JKR and aggregate specifications that are suitable for use as the values are within the JKR Specification.

Table 4. 6 Aggregate Crushing Value Test

Sample	Aggregate Size(mm)	Weight of sample before (g)	Weight retained 2.36mm sieve (g)	Aggregate Crushing Value (%)	JKR Specification

A	20-14	3001.6	453.02	15.09	<30%
B	14-10	3000.24	358.83	11.96	<30%

4.3.5 Los Angeles Abrasion Test

The Los Angeles Abrasion test are used in this study to determine the abrasion value test. The aggregate used on the surface of the pavement surface is subject to the wheel vehicle moving on it. Friction between moving tires and road surfaces causing aggregate abrasion. This effect improves the pavement performance due to dust particles on the road surface. Therefore, the aggregate should have sufficient resistance to abrasion. Table 4.7 below shows that the Los Angeles Abrasion Value is within the range specified in the JKR specification with 21.2%. Therefore, the aggregate is appropriate to be used.

Table 4. 7 Loss Angeles Abrasion Test

Sample	Aggregate Size(mm)	Weight of Crushed Aggregate (g)			%Loss	JKR Specification
		Before(m1)	After(m2)	Loss(m3)		
A	20	5001.4	3941.7	1059.6	21.2	<25%

4.4 Laboratory Evaluation (Performance Test)

4.4.1 Marshall Stability Test

A comparison between the result from laboratory test and specification range according to JKR/SPJ/2008 is made. Table 4.8 shows the result which is the comparison between Marshall Test results according to Public Work Department specification. The comparison is between the samples that containing 0.2%,0.3%,0.4%,0.5%,0.6% Steel Fiber and without containing Steel Fiber. Comparison shows that data obtained comply with JKR (2008) road work specification. The data was analyzed and the optimum bitumen content is founded by (Arshad, Shaffie et al.) for control sample is 6.16% by weight of total mix was used for Stone Mastic Asphalt 20 in this research. It is shown that additional of steel fibers in the mixture gives positive stability impact

Table 4. 8 Marshall Stability Test

Steel Fiber Content	OBC	VFB	VTM	Flow (mm)	Stiffness(kg/mm)
0%	6.2	0	12.9	16933	859.6
0.2%	6.2	3.8	11.2	22553	1062.8
0.3%	6.2	5.2	12.1	19888	1055.1
0.4%	6.2	6.9	11.9	20637	1052.4
0.5%	6.2	8.6	11.7	17160	868.9
0.6%	6.2	11.3	10.5	17233	866.9

Table 4.9 present the results of Marshall analysis for different Steel fiber contents. It shows that there was a slightly increase with 24.92% from 16933 to 22553 in stability at 0% to 0.2% fiber content. Hence, the specimen is proved met the requirement of the Public Work Department (2008). This is due to steel fiber in small amount in the mix, which affects by having a point of contact between the aggregates thus leading to good stability values. The addition of steel fiber in table 4.9 shows that the increase in the content of steel fiber in the mixture, the voids in the mixture also decrease. Mixes with higher fiber content experiencing higher compact ability and therefore the air voids might be decreased too. In conclusion, not all parameters met the requirement of Public Work Department (2008), only stability and stiffness met the requirement given.

Table 4. 9 Comparison between Marshall Test Results According to Public Work Department (2008)

Parameters	Wearing Course
Stability,S	>6200N
Flow,F	2.0-4.0 mm
Stiffness, S/F	>250 kg/mm
Air Void in Total Mix, VTM	3.0-5.0%
Void Filled with Bitumen, VFB	75-85%

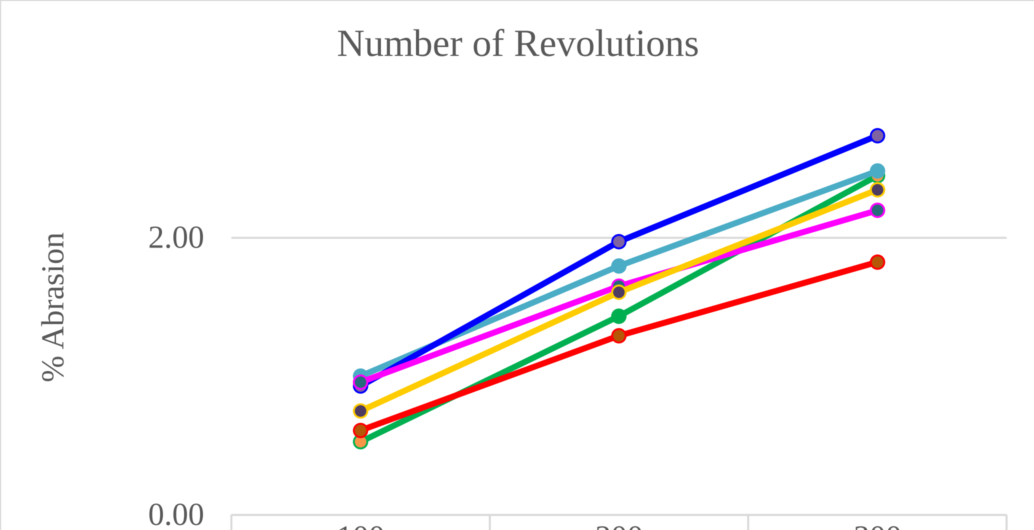
4.4.2 Los Angeles Abrasion Test

Los Angeles Abrasion Machine is used to determine the abrasion loss for the specimens. Abrasion test was conducted to determine the asphalt mixture with the addition of steel fiber could enhance the performance of the stone mastic asphalt even if the road pavement was used many times by the vehicles. The test are conduct three time each specimens to undergo 100,200 and 300 revolutions. Table 4.10 below shows the data of the percentage of abrasion loss that has been obtained from the test for a sample at different percentage (0%,0.2%,0.3%,0.4%,0.5%,0.6%) of steel fiber content for all revolutions.

Table 4. 10 Loss Angeles Abrasion Test

No of Revolutions	**% Abrasion**					
	0%SF	**0.2%SF**	**0.3%SF**	**0.4%SF**	**0.5%SF**	**0.6%SF**
100	0.53	1.00	0.93	0.61	0.96	0.75
200	1.43	1.80	1.97	1.29	1.65	1.61
300	2.45	2.48	2.74	1.83	2.20	2.35

Figure 4.1 shows that the increment in the addition of steel fiber reduced Los Angeles Abrasion loss after 300 turns until reached the optimum fiber content and then increase back. The result shows that 0.4% was the best value for additive to add on in the asphalt mixtures followed by 0.5% and 0.6%. The addition of steel fiber gives a better cohesiveness and the abrasion of Stone Mastic Asphalt (SMA) mixture, make the surface more durable in order to accept higher forces due to traffic loads at 0.4% and 0.5% addition of steel fiber as compared to the origin mixtures without addition of steel fibers with improvement of 33.9% and 11.4% respectively has been proved. This proved that the addition of steel fiber give better cohesiveness and the abrasion of Stone Mastic Asphalt (SMA) mixture, making it stronger in order to accept higher forces due to traffic loads as compared to the mixture without steel fibers.



	100	200	300
0% CF	0.53	1.43	2.45
0.2% CF	1.00	1.80	2.48
0.3% CF	0.93	1.97	2.74
0.4%CF	0.61	1.29	1.83
0.5% CF	0.96	1.65	2.20
0.6% CF	0.75	1.61	2.35

Figure 4. 1 Percentage of Abrasion vs Number of Revolution

4.4.3 Resillient Modulus Test

Universal Testing Machine was used to achieve the total resilient axial deformation that response from a specimen. The indirect tension was used to investigate the resilient modulus of the specimen. In the test, haversine waveform was applied together with compressive loads (Arshad, Masri et al. 2017). Table below shows the data of mean of resilient modulus test that has been obtained from Universal Testing Machine (UTM) for a sample at different percentage (0%,0.2%,0.3%,0.4%,0.5%,0.6%) of steel fiber content at two different temperatures, 25℃ and 40℃. The test has been conducted with different cycles which including 1000,2000 and 3000 cycles at two different position. This can differentiate and testing the performance and the strength of the asphalt mixture that incorporated with steel fiber at different temperature since temperature nowadays are unpredictable. The complete result of Resillient Modulus of SMA 20 at 25℃ and 40℃ are as shown in the table below.

Table 4. 11 Resillient Modulus Test at 25℃

% of Steel Fiber Content	Mean Pulse Repetitive Period (ms)		
	1000	**2000**	**3000**
0%	1101	1047	1066
0.2%	1406	1329	1189
0.3%	1610	1065	1191
0.4%	1624	1606	1678
0.5%	2145	2076	2154
0.6%	2133	1094	2061

Table 4. 12 Resillient Modulus Test at 40℃

% of Steel Fiber Content	Mean Pulse Repetitive Period (ms)		
	1000	**2000**	**3000**
0%	289	295	297
0.2%	603	594	582
0.3%	682	641	616
0.4%	693	651	659
0.5%	624	580	555
0.6%	462	379	359

For SMA20 at 25℃, the high value of resilient modulus of the specimen might be due to the increment in the amount of the additive steel fiber resulted, at 1000ms pulse period, the result of resilient modulus for the origin specimen (0% of steel fiber) was 1101Mpa. The highest Mr value obtained at 0.5% of steel fiber was 2145Mpa. Nevertheless, the results for other pulse period did not show any trend of increasing. For SMA20 at 40℃, the resilient modulus value obtained at 0.4% of steel fiber is higher compared to other percentage of steel fibers with value of 693Mpa at 1000ms pulse repetition. At 0.6% addition of steel fibers, the resilient modulus value is at the lowest average value at 3000ms pulse repetition with the value of 359Mpa. In other words, the lower resilient modulus value of the specimen is caused by the increasing of pulse repetition. The average value of resilient modulus at 25℃ for 0.4% was 1624Mpa at 1000ms,1606Mpa at 2000ms and 1678Mpa at 3000ms pulse repetition.

Figure 4.2 and 4.3 shows the results for each of the sample that tested and how the optimum steel fiber content was determined for enhancing the performance of the stone mastic asphalt. The Stone Mastic Asphalt with addition of optimum content steel fibers mixture stiffness properties are presented in figure 4.2 and 4.3 at 25℃ and 40℃, respectively. Comparing to the specimen without fiber content, the results shows the trends where the stiffness is slightly higher for the specimens with addition of fiber contents. The result displayed that, the stiffness value increasing until the optimum fiber content reached and then the result decreases back. The optimum value of fiber content for resilient modulus at temperature of 25℃ were at 0.5% while 0.4% at 40℃. Mixture with 0.5% fiber content revealed higher stiffness modulus compared to mixture with different steel fibers content at 25℃ while 0.4% for 40℃. The modulus elasticity of the specimen is higher, the specimen are randomly oriented at different directions and the ability of extension is lower are the reason of why the resilient modulus increase. High inclusion of fibers will cause the declination in this test that were beyond certain value is thus surface area to be coated by the binder are higher and therefore the specimens may facing less stiffer mix.

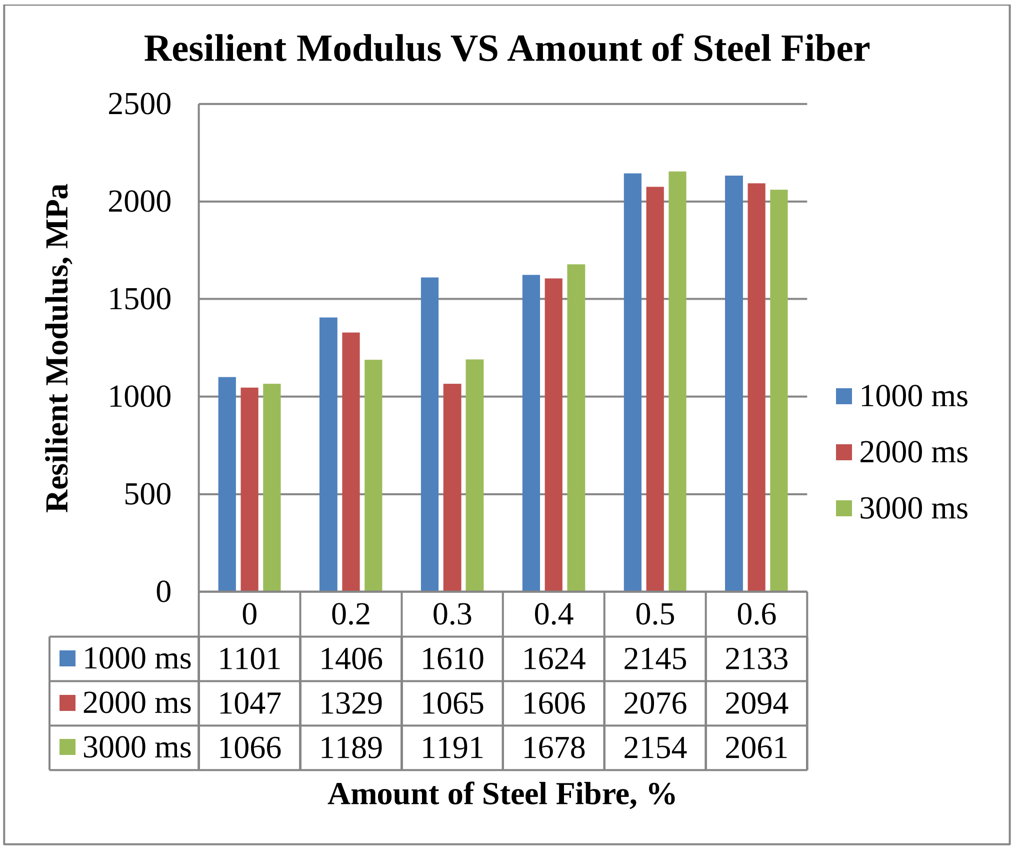


Figure 4. 2 Resillient Modulus vs Amount of Steel Fiber at 25℃

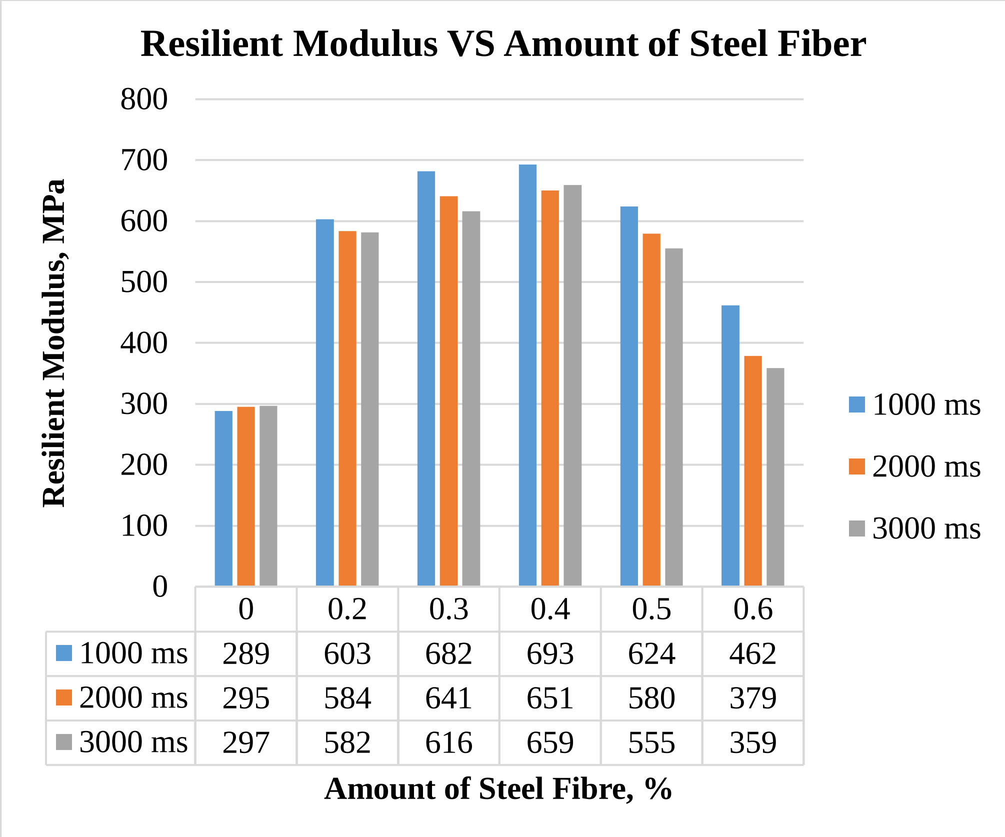


Figure 4. 3 Resillient Modulus vs Amount of Steel Fiber at 40°C

4.4.4 Dynamic Creep Test

Figure 4.4 shows the dynamic creep values that obtained from Universal Testing Machine (UTM) for the sample at different percentage (0%,0.2%,0.3%,0.4%,0.5%,0.6%) of steel fiber content at two different temperatures, 25°C and 40°C. The increment of steel fiber in the mixtures will affect the creep properties of the bituminous mixes in the form of permanent strain.

For SMA20 at 25°C, the permanent strain shows that the addition of 0.2% of steel fibers effect the permanent strain value by decreasing it with 53%. This proved that the small amount of fiber content may influenced the creep properties in the form of permanent strain. Then, the permanent strain value decreases until it reached the optimum fiber content with the increment of fiber content but it increases back with high value of fiber content. The specimen with 0.4% fiber content shows the best result as it is the optimum value of steel fiber in the mixture with the lowest value of 1023.8. comparing to asphalt mixture without steel fibers, the strain value decreases about 53.2,86.3 and 35.1% with The addition of 0.2, 0.3 and 0.6% fiber content to the asphalt mixture. The specimen with 0.5% of steel fibers gives the worst value of permanent strain with differences of 50. Usually, the properties of deformation of a specimen will be slightly improved with addition of small amount of steel fibers as shown in figure 4.4 if it is tested with constant loading and temperature conditions. In conclusion, higher steel fibers portion in the mixture will give a lower resistance to permanent deformation that may cause detrimental effect to the asphalt mixture.

As illustrated in figure 4.5 below dynamic creep test at 40°C, the permanent strain noticeably that the addition of steel fiber was good at 0.4% with 5440.4 strain value and worst at 0.5% with 8372.4 strain value. However, the addition of the steel fiber may enhance the stone mastic asphalt since the result was better than the origin asphalt mixtures (0% of steel fiber) with 8372.4 strain value 11821.2 strain value. The permanent strain was shows that it decreases with the increment of steel fiber until it reached the optimum fiber content and increased back. The addition of steel fiber at 0.3 and 0.4 % shows a good result as compared to the control mix. It reduced the strain value by about 27.2% and 35%. Normally, The dynamic Creep value indicates that the addition of small amount of the steel fiber (0.2%) may enhance the deformation property if it was tested with the same loading and temperature conditions than the mixture with no additional steel fiber. Despite the fact that, the high amount of steel fiber in the asphalt mixtures that gives result higher than the control asphalt mixtures just like 0.5 and 0.6% as in the figure 4.5, the sample will face a detrimental effect as the resistance to permanent deformation getting lower. In Conclusion, the asphalt mixture are less prone to permanent deformation if the value for permanent strain that got from the result were lower.

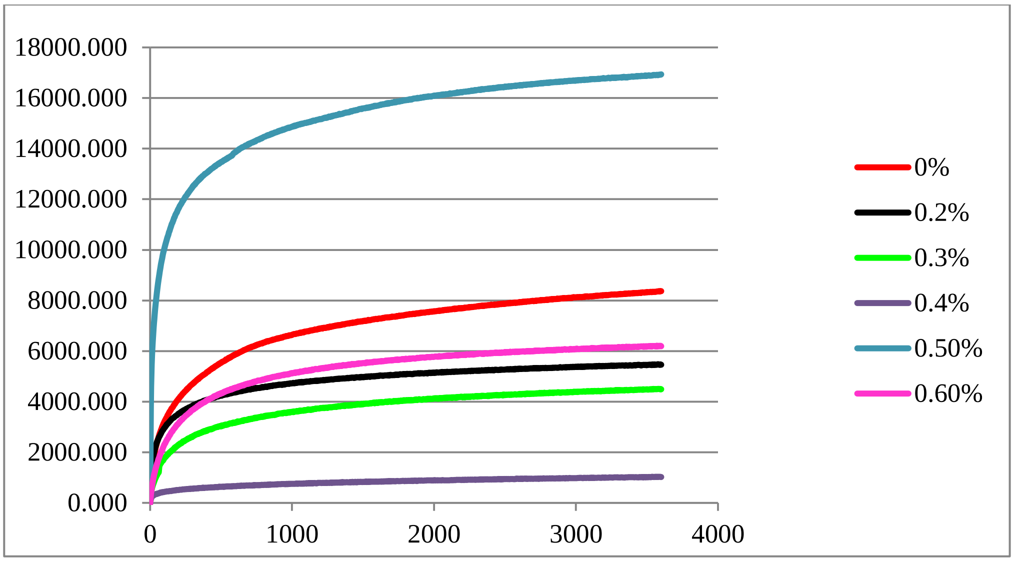


Figure 4. 4 Strain vs Cycle(s) at 25°C

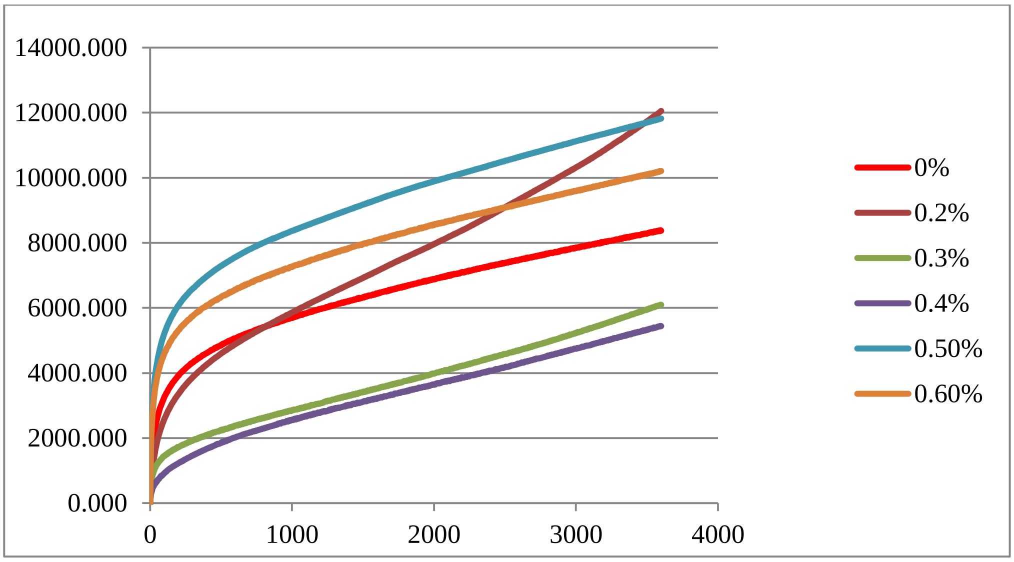


Figure 4. 5 Strain vs Cycle(s) at 40°C

4.5 Optimum Fiber Content Determination by Ranking

The value of the strength is higher when the value of the Steel Fiber reached the optimum content needed. In this chapter also has discussed about the result. The performance of the Pavement Modifier is better than the origin asphalt mixed at 0.4% by ranking. The lower the total value for all results, the better the percentage of the additive in the mixture. Results are analyzed to determine whether the results met the objectives of this study. Finally, all results already met the objectives for this research.

Table 4. 13 Ranking of Performance Test

Percentage of Steel Fiber Content(%)	**0**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**
Performance Test						
Stiffness	6	1	3	2	4	5
Density	6	2	5	4	3	1
Stability	6	1	3	2	5	4
LA Abrasion	4	5	6	1	2	3
Resillient Modulus at 25℃	6	5	4	3	1	2
Resillient Modulus at 40℃	6	4	2	1	3	5
Dynamic Creep at 25℃	5	3	2	1	6	4
Dynamic Creep at 40℃	4	3	2	1	6	5
Total	43	24	23	15	30	29

CHAPTER 5

CONCLUSION

5.1 Introduction

These studies that have been conducted have focused on the performance of stone mastic asphalt that incorporated with steel fiber on its strength in reinforcing the pavement performance and service life. The addition of steel fiber in the asphalt mixtures meets the objectives of this research to determine the optimum Steel Fiber content for Stone Mastic Asphalt 20 by evaluating the performance test and evaluating the mechanical performance of Stone Mastic Asphalt 20 incorporating Steel Fiber. the following conclusions can be made:

I. For Los Angeles Abrasion Test, it has been proved that the addition of mineral steel fiber had enhanced the cohesiveness and the abrasion of Stone Mastic Asphalt (SMA) mixture, make the surface more durable in order to accept higher forces due to traffic loads at 0.4% addition of steel fiber as compared to the control asphalt mixtures with improvement of 33.9% compared to origin mix.

II. Resillient modulus at 25°C for the sample with steel fiber stated the highest value,2145Mpa at 0.5% with increasing of 48.7% as compared to the control asphalt mix. On the other hand, resilient modulus at 40°C stated the highest value at 0.4% steel fiber content. The value are 693,651 and 659 for 1000ms, 2000ms and 3000ms, respectively.

III. The result obtained from dynamic creep test 25℃ and 40℃, the permanent strain noticeably that the addition of steel fiber was good at 0.4% and worst at 0.5%. It reduces the strain value by 35% at 3600 cycles as compared to 0% steel fibre content mix for 40℃.

IV. Optimum fiber content is determined by ranking for all performance test. The optimum fiber content is at 0.4%.

5.2 Recommendation

Based on laboratory investigations and analysis that has been done, it shows that the ability of steel fibers in order to withstand the pressure occurring at the surface layer of pavement, which are directly subjected to the impact of traffic loads that can be the factor affecting the strength of the mixtures. According to the previous studies and also this study, several features of hot mix asphalt (HMA) binders and mixtures have been described, but there are still several unknown parameters should be explored. To further refine this FYP, there are several recommendations that would be suggested. The following topics should be investigated to add on to the findings of this research:

I. Synthetic fiber are another example of additive that can be used to evaluate the performance of hot mix asphalt mixtures at different compacted temperature.

II. Further research using other types of asphalt additive such as asbestos and sources of virgin to investigate the level of the effectiveness of the Steel fiber.

III. Use the different gradation of Stone Mastic Asphalt such as SMA14 that can be compared the characteristics with SMA20.

IV. Drain-down test should be conducted in order to evaluate the drain down content within the range as mentioned in JKR/SPJ/2008.

V. Conduct Rutting resistance test by using Steel fiber and other asphalt additive such as glass fiber to investigate the performance of the Steel fiber in reducing the rutting potential on the pavement surfaces.

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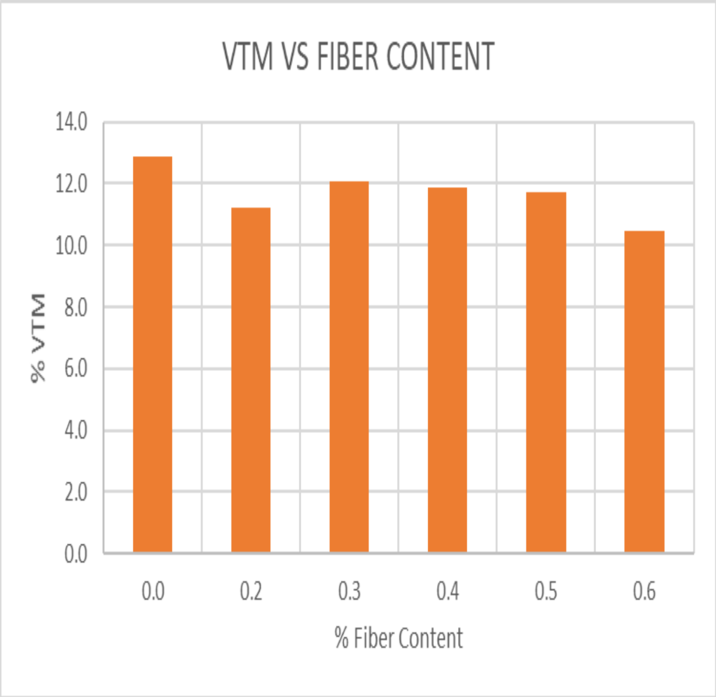
APPENDIX A
SAMPLE APPENDIX 1

LOS ANGELES ABRASION TEST

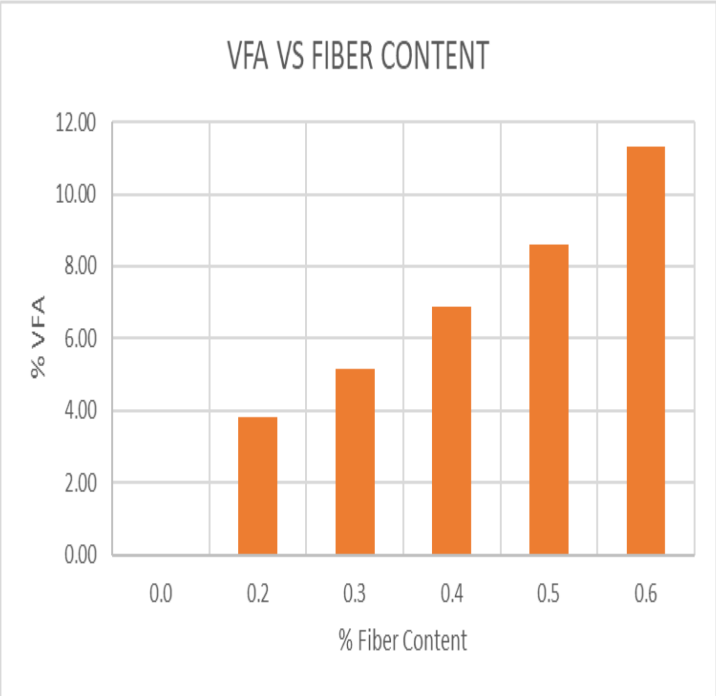
Sample	Weight of sample before,W1 (g)	Weight of sample after, W2 (g)			% abrasion		
		100 rev	200 rev	300rev	100 rev	200 rev	300 rev
S1 (0%)	1239.71	1231.9	1215.37	1198.01	0.63	1.96	3.36
S2 (0%)	1240.67	1235.39	1229.47	1221.65	0.43	0.90	1.53
AVERAGE	**1240.19**	**1233.645**	**1222.42**	**1209.83**	**0.53**	**1.43**	**2.45**
S1 (0.2%)	1306.33	1292.37	1282.5	1275.5	1.07	1.82	2.36
S2 (0.2%)	1293.52	1281.43	1270.66	1259.82	0.93	1.77	2.61
AVERAGE	**1299.93**	**1286.90**	**1276.58**	**1267.66**	**1.00**	**1.80**	**2.48**
S1 (0.3%)	1312.43	1298.25	1283.31	1271.82	1.08	2.22	3.09
S2 (0.3%)	1342.82	1332.29	1319.57	1310.75	0.78	1.73	2.39
AVERAGE	**1327.63**	**1315.27**	**1301.44**	**1291.285**	**0.93**	**1.97**	**2.74**
S1 (0.4%)	1281.90	1280.06	1272.79	1265.36	0.14	0.71	1.29
S2 (0.4%)	1283.40	1269.59	1259.34	1253.12	1.08	1.87	2.36
AVERAGE	**1282.65**	**1274.83**	**1266.065**	**1259.24**	**0.61**	**1.29**	**1.83**
S1 (0.5%)	1255.97	1245.14	1238.33	1232.7	0.86	1.40	1.85
S2 (0.5%)	1260.47	1247.19	1236.57	1228.43	1.05	1.90	2.54
AVERAGE	**1258.22**	**1246.17**	**1237.45**	**1230.57**	**0.96**	**1.65**	**2.20**
S1 (0.6%)	1267.72	1258.25	1244.84	1233.13	0.75	1.80	2.73
S2 (0.6%)	1281.33	1271.68	1263.22	1256.1	0.75	1.41	1.97
AVERAGE	**1274.525**	**1264.965**	**1254.03**	**1244.62**	**0.75**	**1.61**	**2.35**

NO REV	% ABRASION					
	0% CF	0.2% CF	0.3% CF	0.4%CF	0.5% CF	0.6% CF
100	0.53	1.00	0.93	0.61	0.96	0.75
200	1.43	1.80	1.97	1.29	1.65	1.61
300	2.45	2.48	2.74	1.83	2.20	2.35

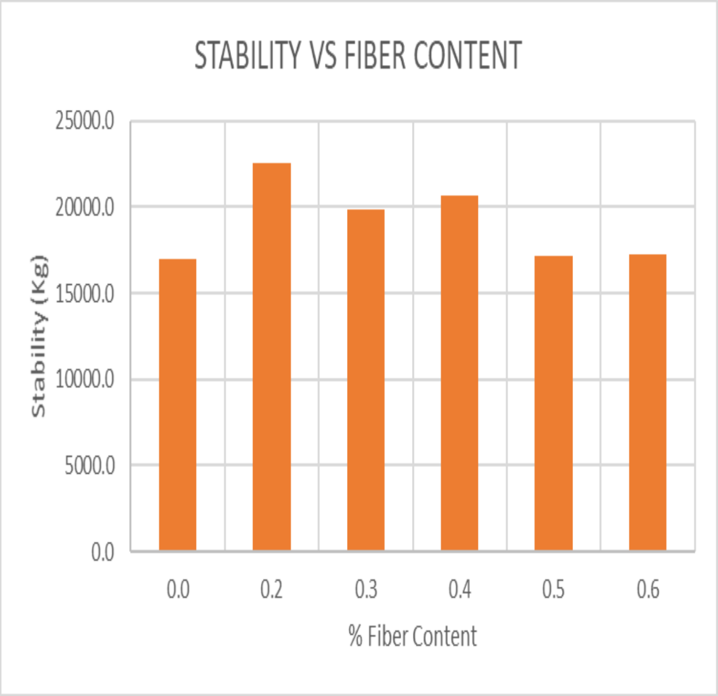
MARSHALL STABILITY TEST



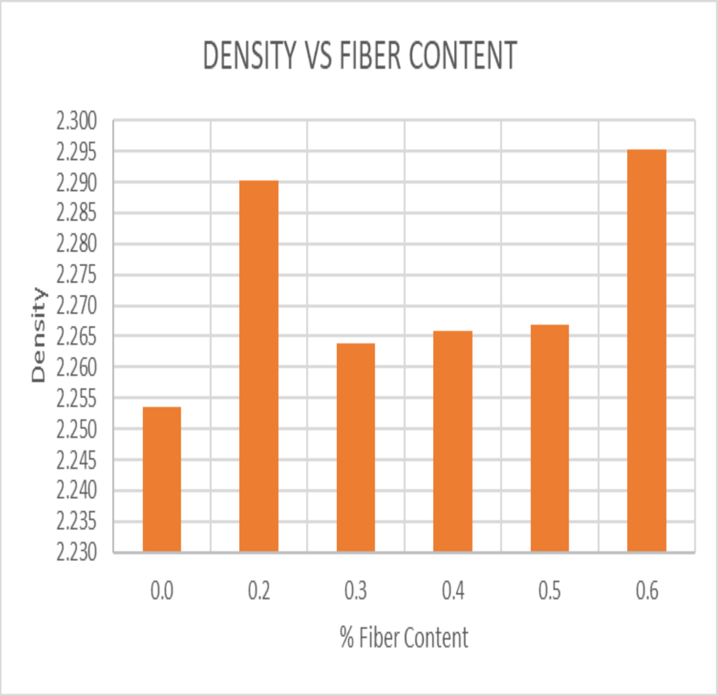
% Fib	VTM
0.0	12.9
0.2	11.2
0.3	12.1
0.4	11.9
0.5	11.7
0.6	10.5



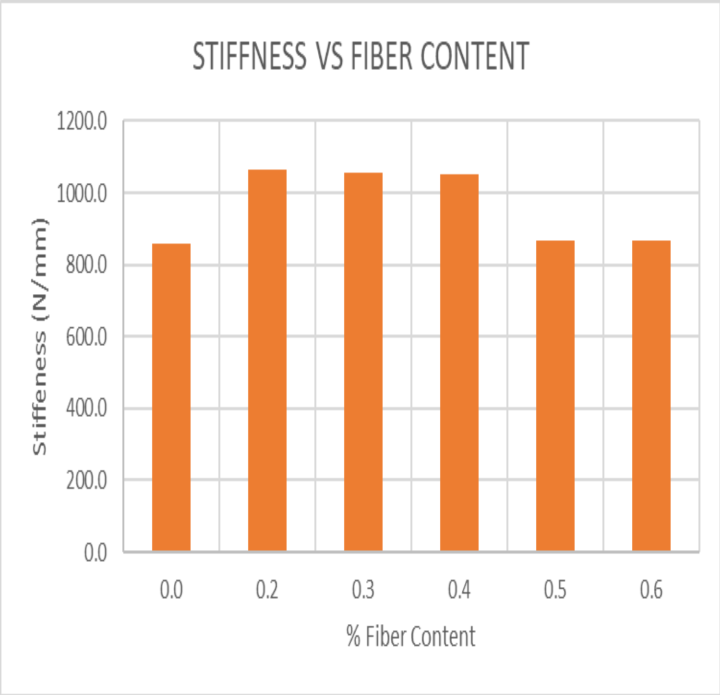
% Fib	VFA
0.0	0.00
0.2	3.82
0.3	5.17
0.4	6.89
0.5	8.59
0.6	11.32



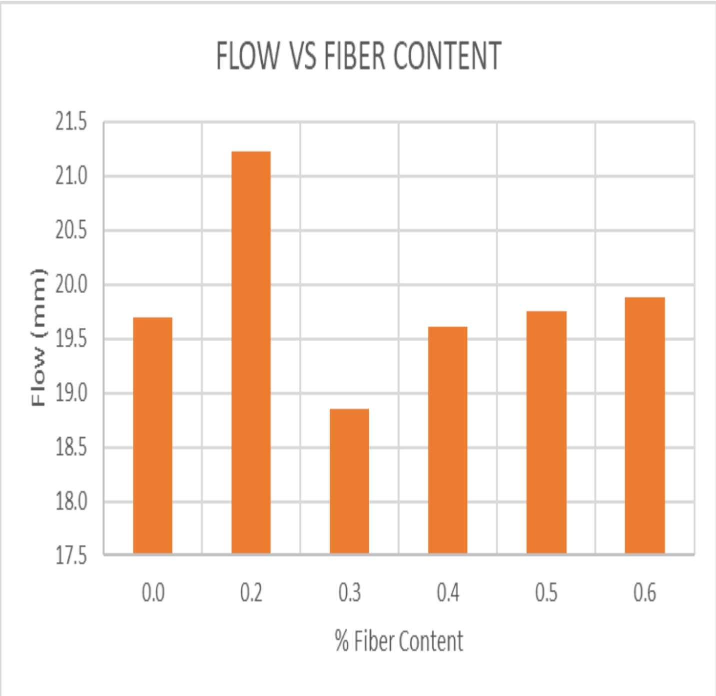
% Fib	Stability
0.0	16933.5
0.2	22552.5
0.3	19888.1
0.4	20636.7
0.5	17160.0
0.6	17233.4



% Fib	Density
0.0	2.254
0.2	2.290
0.3	2.264
0.4	2.266
0.5	2.267
0.6	2.295



% Fib	Stiffness
0.0	859.6
0.2	1062.8
0.3	1055.1
0.4	1052.4
0.5	868.9
0.6	866.9



% Fib	Flow
0.0	19.7
0.2	21.2
0.3	18.9
0.4	19.6
0.5	19.8
0.6	19.9

RESILLIENT MODULUS TEST AT 25°C

Percentage of Fibre Content (%)	Resilient Modulus (MPa)					
	1000 ms		2000 ms		3000 ms	
	0°	90°	0°	90°	0°	90°
0	1069	1132	1045	1048	1077	1054
0.2	1206	1605	1101	1557	1011	1366
0.3	1631	1589	1106	1024	1051	1331
0.4	1864	1383	1854	1358	1987	1368
0.5	2204	2085	2063	2089	2229	2078
0.6	2168	2097	2160	2027	2103	2019

% FC	Resilient Modulus, Mpa		
	1000	2000	3000
0	1101	1047	1066
0.2	1406	1329	1189
0.3	1610	1065	1191
0.4	1624	1606	1678
0.5	2145	2076	2154
0.6	2133	2094	2061

RESILLIENT MODULUS AT 40°C

Percentage of Fibre Content (%)	Resilient Modulus (MPa)					
	1000 ms		2000 ms		3000 ms	
	0°	90°	0°	90°	0°	90°
0	278	299	297	293	292	301
0.2	621	585	590	577	588	575
0.3	808	556	787	495	752	480
0.4	635	751	612	689	627	691
0.5	660	588	629	530	670	440
0.6	469	454	378	379	357	360

% FC	Resilient Modulus, Mpa		
	1000	2000	3000
0	289	295	297
0.2	603	584	582
0.3	682	641	616
0.4	693	651	659
0.5	624	580	555
0.6	462	379	359

DYNAMIC CREEP TEST AT 25°C