PERFORMANCE OF STONE MASTIC ASPHALT INCORPORATING KENAF FIBRE

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ABSTRAK

Batu Mastic Asfalt (SMA) mengandungi jumlah agregat yang tinggi sehingga ia mempunyai interlocking yang lebih baik disebabkan oleh batu itu untuk menyentuh batu tetapi mudah tersentuh untuk mengikat masalah. Oleh itu, matlamat kajian ini adalah untuk menggunakan peratusan Kenaf yang berlainan dalam Asfalt Batu Mastic untuk mengatasi isu-isu yang berkaitan dengan Asfalt Batu Mastic seperti rutting dan retak disebabkan oleh jumlah trafik yang tinggi dan cuaca yang melampau. Antara ujian yang terlibat ialah LA Abrasion, Kestabilan Marshall, Modulus Berkekalan, dan Creep Dynamic. Dari hasilnya, ia menunjukkan bahawa penambahan serat 0.2% menyumbang kepada lelasan nilai terendah. Walaupun, serat 0.2% menghasilkan kepadatan tertinggi. Ia dapat dilihat 0.6% daripada serat Kenaf menghasilkan nilai modulus yang paling berdaya tahan. Creep dinamik juga menunjukkan nilai yang signifikan dalam penambahan 0.2%. Oleh itu, dapat disimpulkan bahwa keberadaan serat mampu meningkatkan prestasi SMA yang jelas misalnya, ketumpatannya. Untuk kajian masa depan, disarankan untuk menganalisis prestasi SMA dari segi rintangan rayap, Kestabilan Marshall, dan rintangan rutting SMA dengan kewujudan serat Kenaf untuk membuktikan kebolehpercayaannya dalam pelbagai aplikasi dalam campuran asfalt.

ABSTRACT

Stone Mastic Asphalt (SMA) contains a high amount of aggregate making it has a better interlocking due to the stone to stone contact but it is susceptible to binder drain down problems. Thus, the aim of this study is to utilize different percentages of Kenaf fibre in Stone Mastic Asphalt to overcome issues related to Stone Mastic Asphalt such as rutting and cracking due to high traffic volumes and extreme weather. Among the test involved were LA Abrasion, Marshall Stability, Resilient Modulus, and Dynamic Creep. From the results, it shows that the addition of 0.2% fibre contributes to lowest value of abrasion. While, 0.2% fibre produce the highest density. It could be seen 0.6% of Kenaf fibre producing highest value of resilient modulus. Dynamic creep also shows a significant value in 0.2% addition. Thus, it can be concluded that the existence of fibre is capable in enhancing the performance of SMA which is evident for instance, the density. For future study, it is recommended to analyses the performance of SMA in terms of creep resistance, Marshall Stability, and rutting resistance of SMA with the existence of Kenaf fibre in order to prove its reliability in various applications in asphaltic mixture.

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LIST OF SYMBOLS

C	Celcius
MPa	MegaPascal
N/mm2	Newton per millimetres square
N	Newton
Kg	Kilogram
g	gram
Mm	Millimetres
cm	centimeters

LIST OF ABBREVIATIONS

SMA	Stone Mastic Asphalt
KF	Kenaf Fibre
REV	Number of Revolution
NAPA	National Asphalt Pavement Association
PA	Porous Asphalt
HMA	Hot Mix Asphalt
PWD	Public Work Department
JKR	Jabatan Kerja Raya
AIV	Aggregate Impact Value
ACV	Aggregate Crushing Value
ASTM	American Section of the International Association for Testing Material
BS	British Standard
NF	Natural fibre

CHAPTER 1

INTRODUCTION

1.1 Introduction

The National Asphalt Pavement Association (NAPA) states that Stone Mastic Asphalt (SMA), an asphalt paving mixture, was born in Germany in the 1970s to provide maximum rutting resistance caused by stubborn tyres on European roads, leading to the development of SMA by Strabag, a large German construction company. When studded tyres were no longer permitted, it was found that SMA provided long-lasting pavements that showed such high rutting resistance due to heavy truck traffic and proved extremely effective in wear resistance. Because of their excellent permanent resistance to deformation, several countries are using SMA in their mixes, according to Sara et al.

Because of its production process, SMA ended up costing more than regular dense-graded mixes, so it is recommended to be used in high-volume interstate highways to benefit from its durability and strength. Due to the impressive friction capabilities with tires, it will also increase driver safety; it will also minimize tire noise and reduce reflective cracking. Stone matrix asphalt (SMA) is a gap-graded mix with a high coarse aggregate concentration. They are held together as stabilizers in a thick asphalt film by a rich matrix of mineral filler, fiber or polymer.

They are held together as stabilizers in a thick asphalt film by a rich matrix of mineral filler, fiber or polymer. Rich mortar binder gives the durability. There is better stone-to-stone contact and stronger interlocking due to the high content of coarse aggregate which serves as the structural basis of SMA. Drain down is a major concern related to SMA Mix. Other reasons for introducing new modifiers in asphalt technology are due to technological advancements, fresh material production and advances in asphalt material science (Taherkhani and Afroozi, 2018)

Previous study shows that by adding fibres in stone mastic asphalt, it could enhance their mechanical properties like providing better aggregates contact and reducing binder drain-down. Fiber are mainly used in stone matrix asphalt and gap graded mixtures to prevent the draining out of binder during mixing and compaction (Mohammed, Parry and Grenfell, 2018). In his research paper ' Sound absorption performance of natural kenaf fibers,' Lim et al also states that it has good sound absorption performance in both normal and random sound absorption incidence. This shows that it could also reduce noise in the pavement by adding Kenaf fiber in stone mastic asphalt. SMA texture features good riding quality, improved skid resistance and relatively low noise (Irfan et al., 2019).

1.2 Problem Statement

According to Public Work Department (PWD) weather is one of the main cause for deteriorating road conditions. Not only that, it has been revealed that the road constructed does not follow the specifications as the contractors hired are cutting down on materials and this led to more issues as the road are exposed to increasing traffic volume over the years. Although various approach has been done to increase the awareness on using quality materials in pavement construction, there are still some who refuse making the users of the road pay for the consequences. Instead of lasting for another five or ten years, the road crumbles faster and need regular maintenance.

A potential problem associated with SMA is drainage and bleeding. Bleeding is caused due to difficulty in obtaining the required compaction. Therefore stabilizing additives such as cellulose fibres, mineral fibres or polymers are used to stiffen the matrix thereby reducing the drain down and bleeding significantly (Xavier *et al.*, 2018). Not only that, some of the road designed cannot occupy the heavy traffic load from heavy trailers making the road susceptible to potholes too. Hence, the aim of this study is to enhance the performance of stone mastic asphalt (SMA) utilising Kenaf fibre as an additive.

1.3 Objectives

The aim of the study is to enhance the performance of stone mastic asphalt in terms of cantabro loss, stability, stiffness, density, resilient modulus and dynamic creep with the existence of Kenaf fibre

1) To determine the material properties of penetration grade 60/70 type of asphalt binder and aggregate.

2) To evaluate the mechanical performance stone mastic asphalt by adding Kenaf fibre as an additive.

3) To determine the optimum fibre content (OFC) by ranking table method.

1.4 Significance of Study

Recently, due to the increase of environmental awareness, concern of environmental sustainability, growing global waste problem, initiation of ecological regulations as well as regulations, decrease of fossil fuels, increase of crude oil price have created interest to renewable resources like Kenaf.(Izran *et al.*, 2014). Kenaf fibre has proven to enhance asphalt mechanical properties when used as an additive in previous studies.

Enhancement in SMA could be seen in reducing its drain down properties. The fibers are helpful in improving the stone to stone contact between the aggregates and thus strengthening their bond. Natural fibres have gained attraction since they are extremely affordable, locally available and eco-friendly in contrast to conventional petroleum based synthetic fibres (EsmaeilpourShirvani *et al.*, 2019).

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter mentions literature review on the history of pavement, stone mastic asphalt, its advantages and disadvantages.

2.2 Type of Pavement

Flexible pavement is preferred over others as its adaptability to construction, this would save more time and cost. It also comes in different types and easy to build making the choice over a road be variant and suitable according to its function. Moreover, flexible pavement can be easily opened and patched, making them more maintenance friendly.

A Scottish man named John Metcalfe, born in 1717 and visually impaired at age six, built many miles of roads and bridges in Yorkshire, England. They are built in three respective layers, which consist of large stones, a mixture of road material, and a layer of gravel. Besides him, there are two other Scottish engineers, Thomas Telford and John Loudon McAdam are involved with the first modern roads and come up with the system of raising the foundation of the road in the centre for easy water drainage. While, Telford improved road building further by going in depth in stone thickness, road traffic, road alignment and gradient slopes. This method later became the norm.

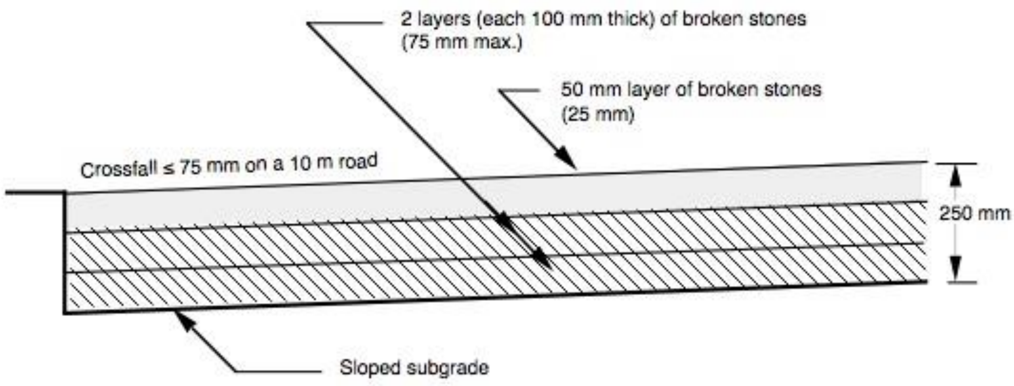

Figure 2.1: McAdam thickness design

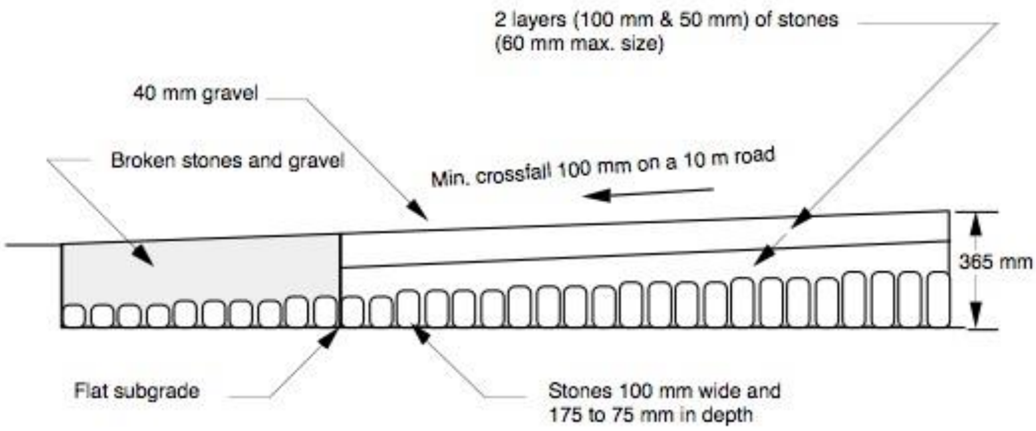

Figure 2.2: Telford thickness design

Pavement surface is a structure that is formed by a mix of processed materials and determined by their respective function. The type of pavement is further divided into flexible pavement and rigid pavement.

2.2.1 Flexible Pavement

Flexible pavement or asphalt pavement is made up of asphaltic or bituminous materials spread over the surface course. It has negligible flexural strength and deforms under the action of load but reverts backto its original shape after load is unloaded.

The load imposed on the surface course is transferred downwards thus the strength of the subgrade influence the thickness of the pavement which in this, the subgrade plays an important role. The load distribution in flexible pavement is through grain to grain transfer. The wheel load acting on pavement is distributed in wider area and stress is reduced with an increase in depth. Since base and surface course is the top layer of the flexible pavement, this layer encounters maximum stress. Strength and performance of flexible pavement are dependent not only on good mix design but also on the load-bearing capacity of the subgrade. A quality subgrade reduces pavement's thickness and contributes toward an economical construction (Gautam *et al.*, 2018).

Figure 2.3: Flexible Pavement Cross-section

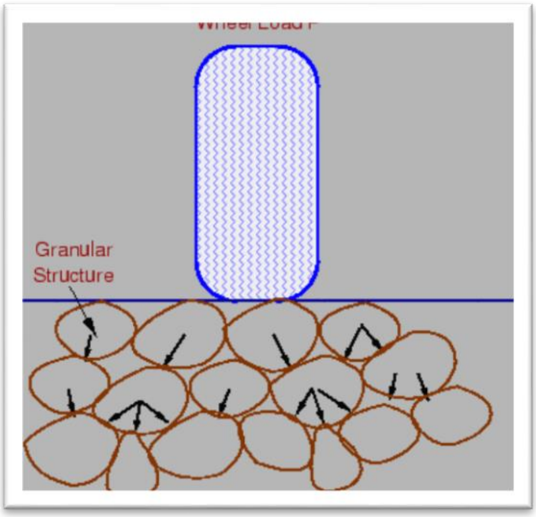

Figure 2.4: Load transfer in granular structure

Load Distribution Concepts

These types of pavements are called "flexible" since the total pavement structure "bends" or "deflects" due to traffic loads. Flexible pavement structure is generally composed of several layers of materials with flexible surface course which can accommodate this "flexing". The function is to distribute imposed wheel loads over large area of natural soils but smaller area of distribution than rigid pavement.

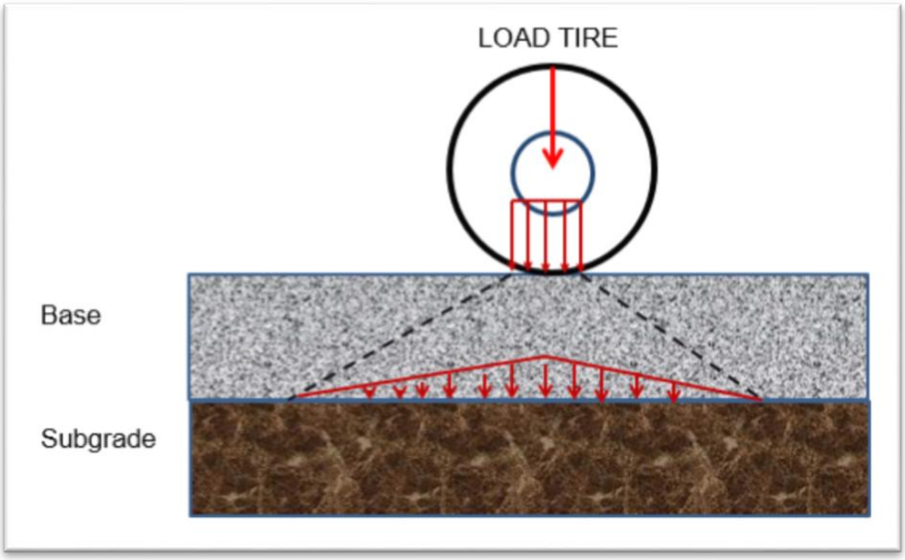

Figure 2.5: Load Distribution Pattern: Flexible Pavement Structure

2.2.2 Rigid Pavement

Rigid pavement is made up of Portland Cement Concrete.Concrete is a composite material, and it is the major constituent of rigid pavement which is usually generated by the homogeneous mixture of aggregates, water and binders (Busari, Dahunsi and Akinmusuru, 2019). It is highly rigid and has high modulus of elasticity. The loads are distributed through bending action over large area of soil. Strength of concrete also must be considered. Rigid pavements are already used on some roads, particularly, on motor highways(Korochkin and Korochkin, 2018).

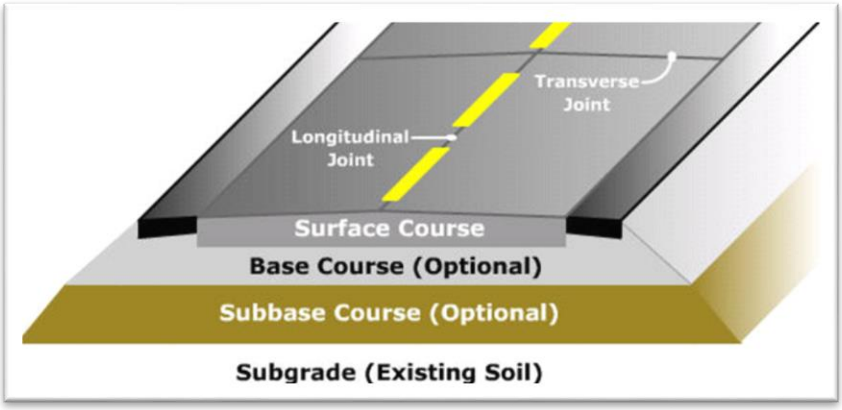

Figure 2.6: Cross section of Rigid Pavement

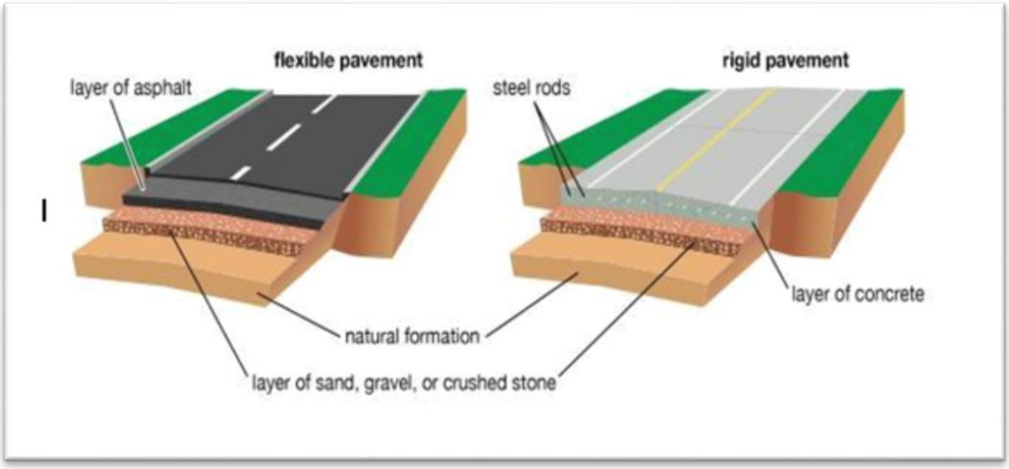

Figure 2.7: Difference between flexible and rigid pavement

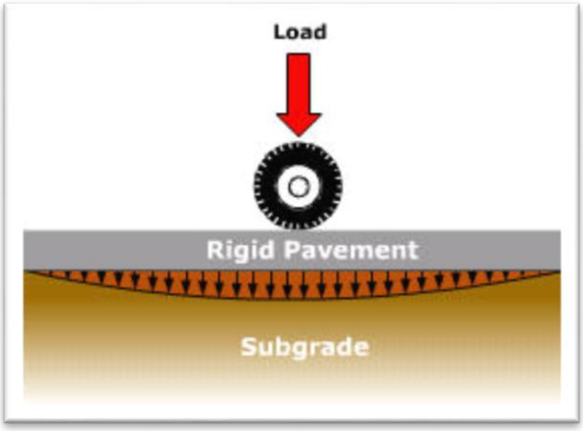

Figure 2.8: Load transfer in Rigid pavement

2.3 Type of Flexible Pavement

There are four types of flexible pavement ; Dense Graded Asphalt, Porous Asphalt, Polymer Modified Asphalt and Stone Mastic Asphalt.

2.3.1 Dense Graded Asphalt

A dense-graded mix is a well-graded HMA mixture intended for common use. When properly constructed and designed, a dense-graded mix is relatively impermeable. Dense-graded mixes are usually referred to by their nominal maximum aggregate size and can further be classified as either fine-graded or coarse-graded.

Dense-graded asphalt are said to be susceptible to rutting as they cannot accommodate high asphalt content which is why there are relatively low amount of asphalt used in dense-graded mixtures but this also makes them more exposed to cracking and more permeable.

Figure 2.9: Typical dense-graded asphalt

2.3.2 Porous Asphalt

Porous Asphalt also known as porous concrete or pervious pavement, allow rainwater to pass through it into the ground below as it has high porosity. In is applied in order to remove excess water on highway which is advantageous for country who have rainfall season. Ravelling, a type of failure that finds its cause within the stone-to-stone contact region, is a dominant defect of porous asphalt pavement resulting in frequent road distress like pit slot and rutting(Zhang *et al.*, 2018). Premature and excessive cracking of pavement will make road agencies cost a lot of money for maintenance, and this may also cause traffic congestion (Li *et al.*, 2018).

Figure 2.10: Porous Asphalt

2.3.3 Polymer-Modified Asphalt

While Polymer Modified Asphalt is an engineered modification to reduce the severity of distress and increase pavement life. When designing an asphalt mixture, it is normally recommended that angular and rough-surfaced aggregates be selected as they tend to improve resistance to permanent mixture deformation (Chen and Wei, 2016). They are seen to perform better at low temperatures and, in addition, some modified binders provide improved stripping (moisture damage) resistance.

The conventional SBS modified asphalt, with SBS content from 3% to 4.5%, cannot prevent asphalt mixture from deforming under shear stress and heavy vehicle load (Lin *et al.*, 2019).Hence why Polymer-Modified Asphalt was introduced. Modified asphalts are often generally called "polymer-modified asphalts." Polymers are probably the most common type of modification, but today's modified asphalts can be produced in several ways. According to the "(MS-4) Asphalt Handbook" of the Asphalt Institute, the modifiers and additives used to boost performance include polymers, chemical modifiers, extenders, oxidants and antioxidants, hydrocarbons and anti-stripping additives.

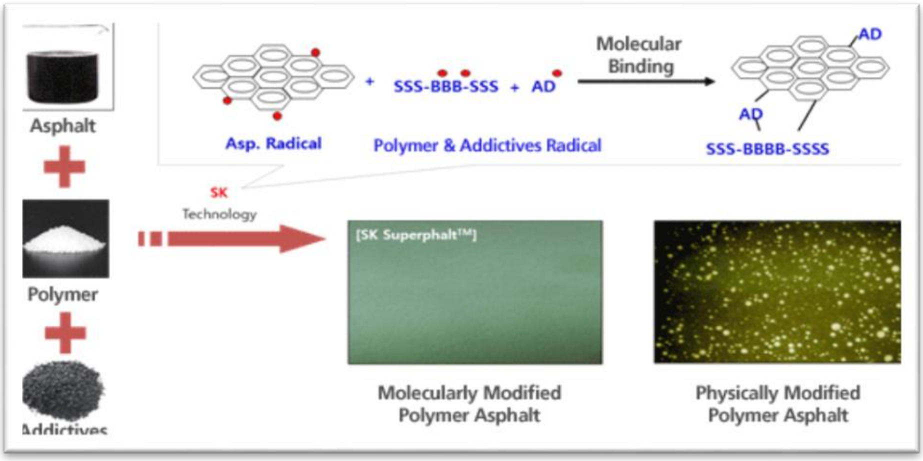

Figure 2.11: Polymer-Modified Asphalt

2.3.4 Stone Mastic Asphalt

SMA consists of crushed fine (sand) and coarse aggregates, bitumen, stabilizing agents and mineral fillers. The stone skeleton mixture provides a gap-graded stone-on-stone texture tolerating heavy loading by frequent vehicle traffic on the road. This type of structure strengthens the pavement's resistance against rutting and enhances its durability in continuous and long-term stress. The aggregates used in SMA should be cubic shaped and rough textured to resist rutting and movement. Besides that, it must has high resistance to polishing and abrasion.

Stone Mastic Asphalt are more suitable for heavy traffic road since it is most deformation resistant and has durable surfacing material. Previous study has been conducted on SMA in which the SMA Mix contains cellulose or mineral fiber, no difference was found in the moisture susceptibility and permanent deformation.

Compared to Hot Mix Asphalt (HMA), SMA is able to prolong the performance life by 30% to 40%.To provide a better, safer road surface condition for users, SMA has been involved in a variety of experiments involving modifying the binder, adding different type of additives and filler just so that its performance could be enhanced. Not only for the sake of stone mastic asphalt, these studies are done to reduce pollution to the environment by incorporating waste materials, natural fibers just to prevent more damage to the environment.

Figure 2.12: Typical Stone Mastic Asphalt surface

2.4 Overview of Stone Mastic Asphalt

Xavier et al., in her paper state that SMA is a gap graded mixture containing 70-80% coarse aggregate of total aggregate mass, 5-7% of binder, 8-12% of filler, and about 0.3-0.5% of fiber or modifier. Thus use of high concentration of coarse aggregate provides better rut resistance and provides skid resistance. Due to high content of bitumen it fills the voids between the aggregates effectively and binds them together, thus contributing to its durability from premature cracking(Xavier *et al.*, 2018).

In addition, SMA mixtures are also known for other advantages, namely their excellent macrotexture in which decreasing the water spray on wet surfaces and reducing the noise furthermore increased their fatigue life(Fernandes, Silva and Oliveira, 2018). For this research we follow the design specified in JKR/SPJ/2008-S4.

Next, rutting and fatigue are considered two major distresses that occur in asphalt pavements that we are still trying to reduce up until now. The asphalt binder plays a big role in the performance of asphalt mixture and hence in controlling the two distresses(Al-Khateeb, Khedaywi and Irfaeya, 2018). Rutting is defined as the most common deformation in the wheel path as a longitudinal depression that can also be caused by shear failure of the bituminous concrete layer. Slow moving traffic and high temperatures further foster the development of this type of deterioration. The most asphalt mixture components affecting rutting performance are aggregate gradation and angularity, maximum nominal aggregate size, bitumen stiffness and bitumen content.

Fatigue cracking is a major distress mode that causes premature failure in flexible pavements. This deterioration mode can affect pavement serviceability, structural capacity and appearance. It can be related to poor pavement design, excessive repeated traffic loading and poor material usage.(Klinsky *et al.*, 2018). Three main parameters affecting fatigue cracking are traffic loading, environmental factors and pavement structure(Habibnejad Korayem *et al.*, 2018).

SMA do provide a textured, durable, and rut resistant wearing course as they have a high stability against permanent deformation like rutting and high wearing resistance. They shows slow aging and durability to premature cracking of the asphalt (Xavier *et al.*, 2018). As mentioned earlier, SMA's surface texture characteristics are similar to Open-graded asphalt (OGA) so that traffic-generated noise is lower than that of Dense Graded Asphalt (DGA) but equivalent to or slightly higher than OGA. This study intends to use SMA.

SMA advantages are it is high in stability due to the interlocking between the aggregates particles in form of skeleton compared to conventional mixtures. It also has higher fatigue life and noise reduction properties.

However, SMA does possess some disadvantages when looking back at its cost of production. Although it could be reduced, SMA are known for its risk in binder drainage due to its high binder content which could occur during transportation to the site. Low skid resistance also exists as one of its problems.

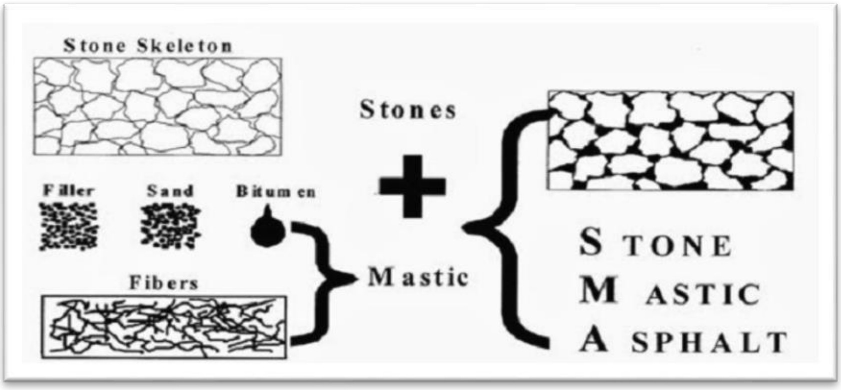

Figure 2.13: Constitution of SMA

2.5 Fibres

Fibres could be found among us in daily lives, for example cellulose which is a primary component of plant cell walls and vegetables. As a high-strength, light-weight and reinforced material, fiber is used to significantly improve the performance and extend the service life of asphalt pavement. Much research has been carried out around the world on this use of fiber and when using fibers, mostly the effect on the rheological properties of binder is seen (Arabani and Shabani, 2019).

At present, the most commonly used road fibers are polyester fiber, basalt fiber, glass fiber and lignin fiber(Chen *et al.*, 2019). Utilization of fibers in asphalt mixtures produces improvement in the behaviour of asphalt pavements, resulting in extending the service life which is considered a great economical feature(Luo *et al.*, 2019). The benefits of fibers in rutting improvement can be due to increases in the consistency of the mastic and lock mechanism between aggregates(Morea and Zerbino, 2018).

2.5.1 Type of fibres

There are natural forms of fibers that are man-made like nylon, acrylic and other plants and animals. Natural fibre has been known as green material ecologically due to its biodegradable properties(Chin *et al.*, 2018).The mechanical properties of natural fibre are highly dependent on shape, strength and size affected by cultivation environment(Mahzabin *et al.*, 2018). The applications of natural fibers are growing in many sectors such as furniture, construction, automobiles and packing due to their low cost, low weight and less damage compared to synthetic fibers(Krishna and Kanny, 2016). Not only that, natural fibres are used in fibre-reinforced polymer and is the dominant load transfer component in fibre-reinforced polymer composites(Anuar *et al.*, 2019).

There are many natural resources for natural fibres but due to limitation of time, technology and funds that is why natural fibres are under developed but there are some companies that have venture out to explore the advantages of natural fibres by producing them in different forms and sizes. In addition, natural fibers can be a suitable comparator with synthetic fibers, such as glass, in many ecological characteristics but not in terms of mechanical strength. Natural fiber applications are growing in many sectors such as furniture, construction, automobiles and packaging due to their low cost, low weight and less damage compared to synthetic fiber. Natural fibers contain cellulose, hemicelluloses, pectins and lignin and are rich in hydroxy1 groups; natural fibers tend to be strong polar and hydrophilic materials while polymer materials are polar and show significant hydrophobicity.

A synthetic fiber consists of various chemical substance variants, hence the term synthetic. The properties of fiber-reinforced composite materials are controlled by the following factors: (1) magnitude and proportion of fiber-matrix elasticity; (2) type and properties of the matrix, such as ductile or brittle; (3) fiber content, length and orientation; and (4) fiber-matrix interface bond strength. (Ahmad, Hamid and Osman, 2019). Synthetic fibers especially glass fibers have been used as reinforcement materials initially, however glass fibers have some shortcomings when compared to NF(Sreenivasan *et al.*, 2018).

There have been a large number of fiber-modified asphalt binders and 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 raveling(Slebi-acevedo *et al.*, 2019). Natural fibre possess some good advantages compared to synthetic fibre like availability in large amounts, low cost, low density, renewable, biodegradable, less skin and respiratory irritation (Hussein, 2017). Fibers also could reduce reflective cracks in asphalt mixtures(Tanzadeh *et al.*, 2019).

2.5.2 Steel Slag

The iron and steel industry is one of China's primary economic structure sectors. Steel slag is a solid waste by-product during the steel-making process when using lime to extract the impurities and its emissions account for about 10 percent to 5 percent of steel production. With the development of iron and steel industry in China in recent decades, steel slag production too has increased rapidly. If a strategy for dealing with steel slag by-products cannot be developed in a timely and effective manner, they will occupy a considerable amount of precious land resources and cause environmental pollution due to the toxicity from the metals.

Figure 2.14: Steel Slag

2.5.3 Cellulose Fibre

Cellulose fibers are fibers made from ether or esters of cellulose that can be obtained from bark, wood or plant leaves or from plant-based material. Natural cellulose fibers are still recognizable as being from a part of the original plant because they are processed only as much as needed to clean the fibers for use. Cotton fibers, for example, look like the soft fluffy cotton balls they come from. Linen fibers look like the flax plant's strong fibrous strands. All "natural" fibers are separated from the parts of the plant that are not used for the end product, usually by harvesting, separating from chaff, scouring, etc. Manufactured cellulose fibers come from plants that are processed into a pulp and then extruded in the same way that synthetic fibers like polyester or nylon are made. Rayon or viscose is one of the most common "manufactured" cellulose fibers and can be made from wood pulp.

Figure 2.15: Cellulose Fibre

2.5.4 Bamboo Fibre

A fiber readily available in nature. Less cost-effective compared to other non-conventional fibers was used as a stabilizer. It is bamboo fiber, which is cellulose fiber extracted from the naturally available stem of bamboo. It has high fiber direction strength, higher tensile strength, flexural strength, and impact strength. Thinness degree of fiber can be easily obtained from it. It is durable in nature, has tenacity and a good value for stability.

Figure 2.16: Bamboo Fibre

2.5.5 Kenaf Fibre

Kenaf is grown for its fiber in India, Bangladesh, the United States of America, Indonesia, Malaysia, South Africa, Viet Nam, Thailand, parts of Africa, and to a small extent in south Eastern Europe. The stems produce two types of fiber: a coarser outer layer fiber (bast fiber) and a finer core fiber. The bast fibers are used to make ropes. Kenaf matures within 100 to 200 days.

First grown in Egypt over 3000 years ago, the leaves of the kenaf plant were a component of both human and animal diets, while the bast fiber was used for bags, cordage, and sails for Egyptian boats. This crop was not introduced in southern Europe until the early 1900s.

Kenaf is cultivated for its fibre in India, Bangladesh, United States of America, Indonesia, Malaysia, South Africa, Viet Nam, Thailand, parts of Africa, and to a small extent in southeast Europe. The stems produce two types of fibre: a coarser fibre in the outer layer (bast fibre), and a finer fibre in the core.

Today, while the principal farming areas are China and India, Kanaf is also grown in countries including the US, Mexico, and Senegal. In addition, as part of an overall effort to make vehicles more sustainable, Ford and BMW are partly from kenaf making the material for the automotive bodies. The first kenaf implementation within a Ford vehicle was in the 2013 Ford Escape. The BMW i3 uses kenaf in the black surroundings.

Figure 2.17: Kenaf Fibre

2.6 Overview of Kenaf Fibre

Kenaf or its scientific name Cannabinus L. is a source of raw material for pulp, paper and other fibre products. After first being introduced in 2010 as an alternative to tobacco, it is fast becoming the country's third industrial crop after palm oil and rubber. Kenaf comes from the Malvaceae family, which is identical to cotton. The plant stem consists of 65% inner core fiber and 35% outer bast fiber, producing low and high-quality pulp, respectively. (Lim *et al.*, 2018). The different types of stabilizing agents commonly used in SMA are generally expensive, so there is a need to obtain an alternative, lower-cost stabilizer that essentially serves the same purpose, similar to that obtained by using other commonly used stabilizing additives (Xavier *et al.*, 2018). Natural fibres exhibit low energy consumption, low density, low cost, less abrasive to equipment and carbon dioxide neutral(Sivakumar *et al.*, 2018).

Kenaf fibers, among other types of natural fibers, represent the highest level of carbon dioxide absorption, have low density and high modulus, and require low energy production and useful in the absorption of oil and other organic liquids. They are cost-effective, abundant, non-abrasive, formable and safe for health.(EsmaeilpourShirvani *et al.*, 2019). Kenaf bast fibers are now widely used as food-protective packaging, composites, textiles and filters. Kenaf crop production is rapid as it has a high growth rate and low crop rotation. The plant can reach a height of 4 to 5,6 m within 4–6 months, and during this time the crop is ready to be harvested.(Lim *et al.*, 2018).

2.7 Gap of Research

Table 2.1 shows the previous research that relates with the study with their gaps.

Table 2:1: Gap of Research

Title	Author/Year	Description	Gap Of Research
Rutting and Fatigue Properties of Cellulose Fiber-Added Stone Mastic Asphalt Concrete Mixtures	Irfan, M., Ali, Y., Ahmed, S., Iqbal, S., & Wang, H. (2019).	The asphalt concrete material behaves like a viscoelastic material, and its stiffness varies with the temperature. Higher stiffness/modulus in low temperatures (winters) results in fatigue cracking, and lower stiffness/modulus in high temperatures (summers) results in rutting	Cellulose Fibre is used instead of Kenaf Fibre
A Review on Fiber Modified Stone Matrix Asphalt Rose	Xavier, R. M., Martin, B., Babu, L. A., Jose, L. E., & Roy, L. (2018).	The different types of stabilizing agents commonly used in SMA are generally expensive hence there exist a need to obtain an alternative, lower-cost stabilizers that will essentially serve the same objective, in a similar way as obtained by using other commonly used stabilizing additives.	Various fibers are used instead of only one fibre
Improvement of the engineering behavior of sand-clay mixtures using kenaf fiber reinforcement.	EsmaeilpourShirvani, N., TaghaviGhalesari, A., Khaleghnejad Tabari, M., & Janalizadeh Choobbasti, A. (2019)	Kenaf fibers, among the other kinds of natural fibers, represent the highest level of carbon dioxide absorption, have low density and high modulus, and require low production energy. They are cost-effective, abundant, non- abrasive, formable, and safe towards health.	Sand Clay mixtures is used instead of Stone Mastic Asphalt

Mechanical Behavior of Asphalt Mastics Produced Using Waste Stone Sawdust	Al-Khateeb, G. G., Khedaywi, T. S., & Irfaeya, M. F. (2018).	Modification of asphalt binders is done by utilizing several modifiers that are available on a wide spectrum in the industry. Some of these modifiers are manufactured so that they are used in the asphalt technology at a feasible cost. However, other modifiers are waste or recycled materials that can be used in asphalt to serve twofold purpose: (1) enhancing the properties of asphalt and (2) helping to clean environment.	Waste Stone Sawdust is used instead of Kenaf Fibre

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter explains in detail on the methodology to obtain the result/data required. The methodology starts with material preparation and aggregate testing, which covers *Sieve Analysis*, *LA Abrasion Value test*, *Aggregate Crushing Value (ACV), Aggregate Impact Value (AIV), Flakiness and Elongation.* While to determine the asphalt binder physical properties, *Penetration Test*, *Softening Point Test and Ductility Test* is done. Marshall Mix Design is followed to prepare the samples which were further tested by *Marshall Stability test, Resilient Modulus test, and Dynamic Creep test.*

3.2 Flow of Research

Figure 3.1 show the methodology that was used for this study. The research starts from collecting all related information regarding the Rutting Resistance and Resilient Modulus of Stone Mastic Asphalt with Kenaf fibre until the result & analysis of data.

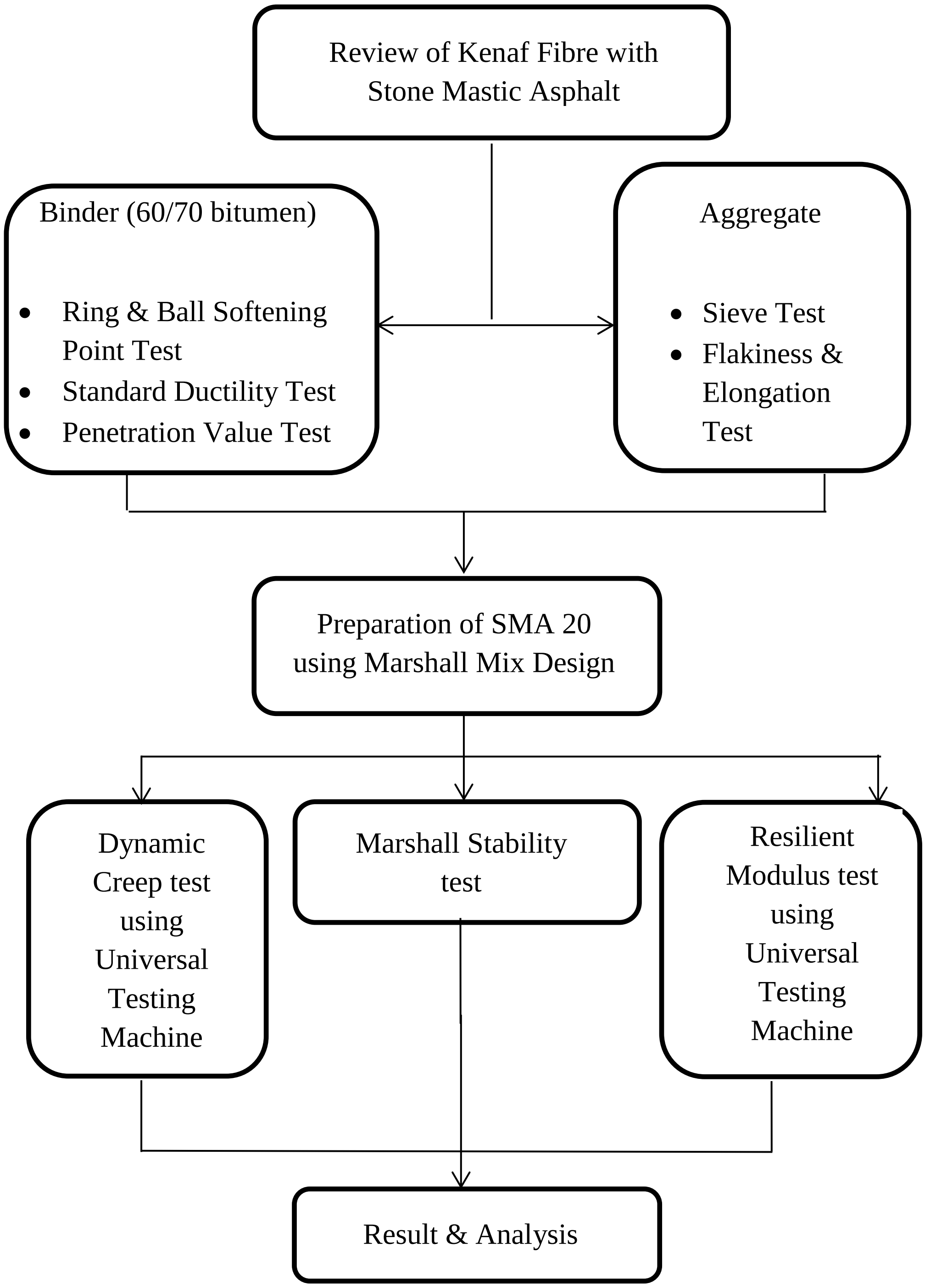

Figure 3.1: Flow of Research

3.3 Material Properties

3.3.1 Type of aggregate

The types of aggregates used in this research are coarse and fine aggregates. For coarse aggregate, it shall be screened crushed hard rock and retained on 5.0 mm sieve opening angular in shape and free from dust, clay, vegetative and other organic matter, and other deleterious substances. As for fine aggregates, they shall be non-plastic and free from clay, loam, aggregations of material, vegetative and other organic matter, and other deleterious substances

3.3.2 Type of asphalt binder

Bituminous Binder. The bituminous binder for use with Stone Mastic Asphalt shall be of performance grade PG76 or higher in compliance with AASHTO Standard M320-02.

3.3.3 Type of mixture

Stone mastic asphalt or SMA is a polymer modified hot bituminous mixture with a large proportion of coarse aggregate and rich bitumen-filler mastic. Generally, SMA comprises approximately over 65% coarse aggregate and a minimum of 8% filler content as per Table 4.7.2.

3.3.4 Type of fibres

There are various types of fibres such as cellulose fibre, steel fibre, bamboo fibre and Kenaf fibre. For this study, Kenaf fibre is used.

3.3.5 Type of design mixture

For Stone Mastic Asphalt (SMA) we use Marshall Mix Design in preparing the sample needed.

3.3.6 Physical properties test

Penetration test, Ductility test and Softening Point test for the bitumen physical properties.

3.3.7 Mechanical properties test

For this research, the following test are done:

i. Resilient Modulus according to ASTM D7369-11

ii. Dynamic Creep according to ASTM D704-15

iii. Marshall Stability according to ASTM D6927

iv. LA Abrasion test according to ASTM C-131

Specification that will be used in this study is in accordance to Malaysia Public Work Department (JKR SPJ 2008)

3.3.8 Binder Test

The bitumen used are Grade 60/70 and tested by the following test which are Penetration Test, Softening Point Test and Ductility Test.

3.3.8.1 Penetration Test

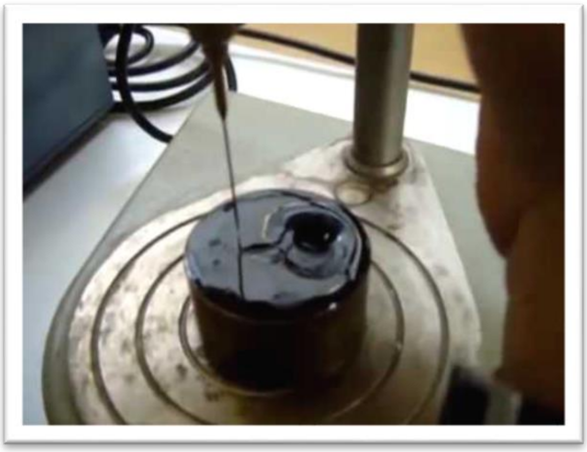

Figure 3.2: Penetration test

The specimens are prepared in sample container as specified (ASTM D5-97) and placed in a water bath at a prescribed temperature of the test for about 1 to 1.5 hours prior the test. The penetration needle is cleaned and fixed into the holder and guide. For normal test, the precisely dimensioned needle is loaded to 100 ± 0.05g. Next, the needle is slowly lowered until its tip just makes contact with its image on the surface of the sample at right angles. Then, the penetrometer dial reading is set to zero. The needle holder is released to penetrate the bitumen for 5 ± 0.1s, while its temperature is maintained at 25℃ ± 0.1℃. The penetration measured in terms of a millimetre (deci-milimetre, dmm). The depth of penetration is read and recorded. Make at least three determinations on specimens at different points and clean the needle before repeating the test.

3.3.8.2 Softening Point Test

Figure 3.3: Softening point test

The bitumen is melted and poured into a pair of ring placed on plate. Thermometer is placed in the center of the ring holder levelled with the bottom of the ring. After the specimen has cooled, the ring is suspended in the distilled water in the beaker at 5℃ ± 2℃. The temperature is maintained at that temperature for 15 minutes. The steel balls are put on the surface of the bitumen in the ring. Then, the bath liquid is stirred and heated to 5℃ ± 2℃ per minutes. When the ball is passed and dropped into the base plate, the temperature is noted.

3.3.8.3 Ductility Test

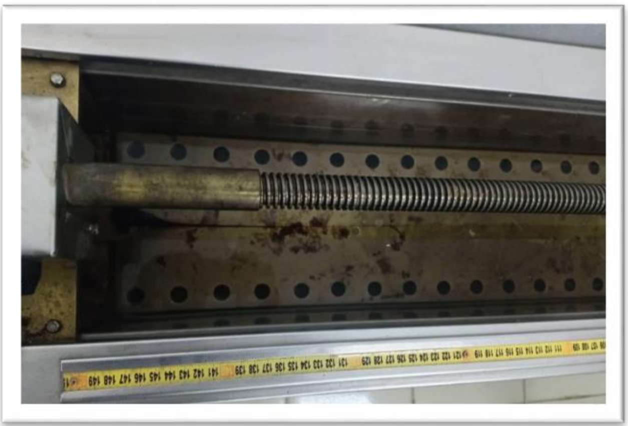

Figure 3.4: Ductility test

This test was conducted at a temperature of 27°C ± 0.5°C. The bitumen is melted at temperature of 75°C to 100°C until it become fluid. The mould is assembled and coated with Vaseline to prevent bitumen from sticking. The mould is then filled until more than level full and leave to cool at room temperature for 30 to 40 minutes. Then, place it in water bath maintained at a specific temperature for 30 minutes. Cut off excess bitumen if present. Place the brass plate and mould with briquette specimen in the water bath and remove the briquette from the plate, detach sidepieces and test the briquette immediately. Attach rings at each end of the clips to the hook in the testing machine and pull the clip apart horizontally until the briquette ruptures. The distance through which the clips have been pulled to produce rupture is the ductility value which is measured in centimetres. It is done to see how much the bitumen will elongates before it breaks and at least three readings are taken for each test. The constant here is the temperature and speed used by the machine itself to test the bitumen. The experiment stops when the sample undergoes failure.

3.3.9 Aggregate Test

3.3.9.1 Sieve Analysis

Sieve Analysis is done by assembling the required sieve size for the experiment and weight each of them before placing the aggregates which have been divided earlier into the sieve and then operate the sieve shaker for at least 5 minutes. The weight of the aggregates retained on each sieve is recorded. This test is done in order to know the aggregate gradation and size.

3.3.9.2 LA Abrasion Value Test

LA Abrasion Value is done by washing and drying the sample (aggregates) to a constant weight. The sample is then placed into the LA Abrasion Machine and after rotated the sample is sieve on a 12mm sieve and the retained sample is washed and dried. The weight of the sample is then taken. The objective of this test is to obtain the Los Angeles Number in the form of percentage wear of aggregates which reflects their resistance to degradation using the Los Angeles testing Machine.

3.3.9.3 Aggregate Impact Value Test

Aggregate Impact Value is done to the sample that passes the 10 mm and 14 mm sieve. The sample is washed and dried before weighted. Then they are filled into the cylindrical measure in three layers, each of the layer is tapped three times by using the tamping rod and the sample in the measure is weighted. After that, the aggregate is transferred to the cup in also three layers and tamped 25 times. The Impact Testing Machine is used to land 15 blows on the sample. Lastly the sample is removed from the cup and sieved through 2.36mm sieve and the fraction passing is noted as weight loss. The objective of the experiment is to determine the aggregate impact value of road stone.

3.3.9.4 Aggregate Crushing Value Test

Aggregate Crushing Value is done similarly to AIV only that the sample just need to be filled into the cylinder by three layers with each layer tamped 25 times and then is placed between the plates of the testing machine. Same as AIV, the crushed sample is also sieved through 2.3mm sieve and fraction passing is noted as weight loss. The objective of this experiment is to determine the mechanical strength of the aggregate

3.3.9.5 Flakiness

This test is used to determine the particle shape of the aggregate and each particle shape being preferred under specific conditions. Flakiness index is the percentage by weight of particles in it, the smallest dimension (i.e. thickness) of which is less than three-fifths of its mean dimension. The test does not apply to materials passing the 6.30 mm test sieve or retained on the 63.00 mm test sieve.

The sample is sieved with the apparatus that consist of a standard thickness gauge of IS sieve sizes of 63, 50, 40, 31.5, 25, 20, 16, 12.5, 10 and 6.3mm. A minimum of 200 pieces of each fraction to be tested is taken and weighed. Each fraction is weighted to an accuracy of at least 0.1% of the test sample in order to separate flaky materials.

Figure 3.5: Flakiness Apparatus

3.3.9.6 Elongation

An aggregate elongation index is the percentage by weight of particles whose largest dimension (length) is greater than one and four-fifth times (1.8 times or 9/5 times) their mean dimension. It is measured on particles passing through 63 mm mesh size and retained on 6.3 mm mesh size.

The presence of elongated aggregates in a mix disturbs the particle packing and creates more space. Elongated particles have a high surface-to-volume ratio that reduces concrete workability. If elongated particles are used for pavement base course construction, they can easily break down under heavy loads that will cause pavement damage. So, it is necessary to know the elongation index of given aggregate mix.

The sample was sieved with the device consisting of a standard thickness gage of 50, 40, 31.5, 25, 20, 16, 12.5, 10 and 6.3 mm IS sieve sizes. A minimum of 200 pieces of each fraction are taken and weighed. Each fraction is then measured individually for length, in a length gauge to separate elongated material.

The pieces of aggregates were collected separately from each tested fraction, which could not be elongated by the specified gauge length with its long side. Then the total weight of aggregates retained from each fraction on the length gauge was determined. The total quantity of elongated material retained by the length gauge was weighed to an accuracy of at least 0.1 percent of the sample weight.

For pavements that are either bituminous or non-bituminous, the coarse aggregate elongation index should not surpass 15 percent. The elongation index is calculated in percentage rounded to the nearest whole number.

3.3.10 Fibre

Kenaf fibre was cut into 1cm in length before mixing it into the mix with different percentage ranging from 0 to 0.6 %. The fiber is weighed from 3g, 4g, 5g, 6g and 7g before added into the mix the following are the properties for Kenaf fibre:

i. Density is 1320 kg/m3

ii. Tensile strength is 260 N/mm2

iii. Moist absorption is 10-12 %

iv. Average diameter of fibre is 67.6 µm

Figure 3.6: Kenaf fibre

3.4 Performance Tests

3.4.1 Marshall Stability

Figure 3.7: Samples for Marshall stability test

This test was conducted on 12 samples with two samples for each percentage of 0%, 0.2%, 0.3%, 0.4%, 0.5% and 0.6% according to ASTM D6927 standard method. Prior to testing, the samples would be conditioned by placing them in a water bath at a temperature of 60 C for 30 minutes. The sample would then be placed on the machine and will be loaded with force required for breaking the sample that would be measured as the Marshall Stability.

3.4.2 Cantabro Loss

Figure 3.8: Sample before abrasion test

Figure 3.9: Samples after abrasion test

As for LA Abrasion test or Cantabro test, there were 12 samples involved for each percentages of Kenaf fibre same as Marshall Stability only that they were put inside the abrasion machine to be rotated for about 300 cycles. The weight and diameter of the sample before testing were taken and their respective weight would be recorded for before and every 100 cycles after until it reaches 300 cycles. It was done according to ASTM C-131 but without the steel balls.

The test is used to analyze sample resistance to abrasion in a specific environment. The importance of abrasion test lies in evaluating the rank of the material in ascending order as it will occur in an abrasive environment. Compared to the original material, the percentage of loss of content judged from the test which is lost when kept under abrasive environment. This comparison will provide materials with the value if abrasion is the major factor that causes material rupture

3.4.3 Resilient Modulus

Figure 3.10: Resilient Modulus set up

The test was done according to ASTM D7369-11 and was conducted at two different temperatures which are 25℃ and 40℃. The temperatures indicates low and high temperature condition. The UTM machine is controlled from the computer and the software used is ITS-Resilient Modulus. Before running the software the Axial force must be offset to zero to prevent the knob from going upward by itself. The lvdt1 and lvdt2 cannot be in negative value prior before test is conducted to prevent inaccuracy of reading.

The test would take approximately 3 hours for 3 samples having a total of 6 samples for each temperature the sample would be tested in two position which are 0 and 90 degree position. The average reading is taken for each sample.

3.4.4 Dynamic Creep

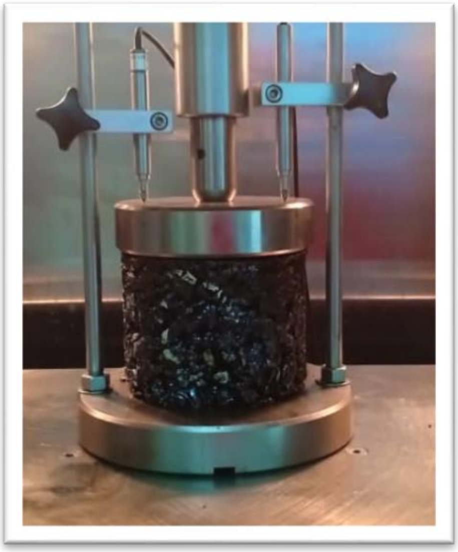

Figure 3.11: Dynamic Creep set up

This test was done by using the UTM machine and a software of permanent deformation on the computer. The sample would be conditioned at a temperature of 40℃ in the machine before being placed into the dynamic creep apparatus. The testing occurred for about 2 hours before the end result is produced on the computer. This test was done according to ASTM D704-15.

CHAPTER 4

RESULT&DATA ANALYSIS

4.1 Introduction

The results for each binder test aggregate test, and performance test are discussed further in this chapter. The properties of binder and aggregates need to pass the specification as stated in JKR-SPJ-2008.

4.2 Materials Properties

The materials properties results shows all pass in accordance to the specification.

4.2.1 Penetration Test

Penetration test shows that the binder falls into the specification which is 65mm. The penetration value shows that it is suitable to use as it falls under the specification. The consistency of bitumen is good and it suitable to use under different climatic conditions and various types of construction.

Table 4:1: Penetration Test Result

Test	**Result**	**Specification**	**Status**
Penetration (mm)	65	60-70	Pass

4.2.2 Softening Point

Softening point or ring and all test indicates at temperature of 47 °C the ball falls from the ring. Higher softening point shows that they will not flow during service. The higher the softening point, the lesser the temperature susceptibility. Bitumen with higher softening point is suitable in warmer region.

Table 4:2: Softening Point Result

Test	Result	Specification	Status
Softening Point (°C)	49	47 min	Pass

4.2.3 Ductility Test

The ductility test also shows a pass in the result as the elongation of bitumen are up until 150 cm only. The bitumen could elongate under traffic load without getting cracked in road construction works.

Table 4:3: Ductility Test Result

Test	Result	Specification	Status
Elongation Of Ductility (cm)	150	100 min	Pass

4.2.4 Sieve Analysis

Sieve analysis is done to obtain the required aggregates mass to be used and falls into the targeted specification.

Table 4:4: Sieve Analysis

ASTM Sieve	Gradation Limit (%)	Targeted Pass (%)	Retained (%)	Mass Retained (g) / 1200g sample
Sieve Size (mm)	SMA 20			
19.0	100	100.0	0	0
12.5	85 – 95	90.0	10.0	120
9.5	65 – 75	70.0	20.0	240
4.75	20 – 28	24.0	46.0	552
2.36	16 – 24	20.0	4.0	48
0.600	12 – 16	14.0	6.0	72
0.300	12 – 15	13.5	0.5	6
0.075	8 – 10	9.0	4.5	54
Pan	0	0.0	9.0 7% - Pan 2% OPC	Pan - 84 Lime - 24

4.2.5 LA Abrasion Value

The test shows a result about 21% showing it pass the limit of LA Abrasion value which is below 25%. This test shows the aggregates toughness and abrasion importance. The percentage of wear due to rubbing action of steel balls and aggregates is used as abrasive charge.

Table 4:5: LA Abrasion Value Result

Sample	**Aggregate size (mm)**	**Weight of Crushed Aggregate (g)**			**% Loss**
		Before (m1)	After (m2)	Loss (m3)	
	20	5001.4	3941.77	1059.63	21.18

LA Abrasion Value (%) = $\frac{weight\ loss\ (m3)}{Initial\ weight\ (m1)}$ x 100

LA Abrasion Value (%) = $\frac{1059.63}{5001.4}$ x 100

= 21.18 %

4.2.6 Aggregate Impact Value

The percentage of loss obtained from this test is 15%. This value indicates the resistance of aggregates to sudden shock or impact. Thus, the aggregate toughness is strong and have sufficient strength.

Table 4:6: Aggregate Impact Value Result

Sample	**Aggegate Size(mm)**	**Weight of Aggregate (g)**			**% loss**
		Before Test (M_1)	Retain at 2.36mm sieve (M_2)	Passing at 2.36mm sieve (M_3)	
A	10	293.66	251.6	43	15

4.2.7 Aggregate Crushing Value

Both of the sample shows results below the aggregate crushing value limit which is 25%. This shows that the aggregates could resist to crushing under a gradually applied load. Crushing value also a measure of the aggregate strength.

Table 4:7: Aggregate Crushing Value

Sample	**Aggregate Size(mm)**	**Weight Of Aggregate before (g) M1**	**Weight Pass Sieve 2.36mm (g) M2**	**Aggregate Crushing Value (%)**
A	20-14	3001.6	453.02	15.09
B	14-10	3000.24	358.83	11.96

4.2.8 Flakiness and Elongation

Both of these test passes with result of 25% and 24.9% respectively since ASTMC131 states that both test should not be more than 25%. The significance of flakiness & elongation index is as follows; the degree of packing of the particles of one size depends upon their shape. Due to high surface area to volume ratio, the flaky and elongated particles lower the workability of concrete mixes. Flaky and elongated particles are considered undesirable for base coarse construction as they may cause weakness with possibilities of braking down under heavy loads. BS-1241 specifies a Flakiness index not exceeding 30% irrespective of the aggregate size.

4.3 Performance Test Results

4.3.1 Cantabro test

In the Cantabro test, the sample is weighed before putting it in the Abrasion machine, there are two sample used for each percentage of fibre of 0%, 0.2%, 0.3%, 0.4%,0.5% and 0.6%. For every 100 rotation the sample is taken out to be weighed until it reaches 300 rotation. From Figure 1 it is shown that 0.2% addition of Kenaf Fibre has the lowest abrasion value compared to the others.

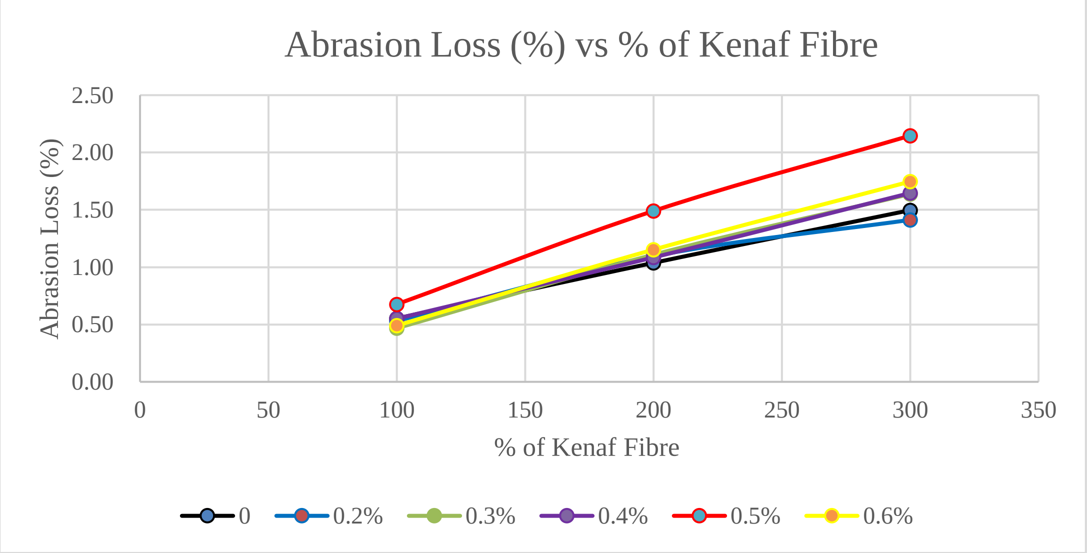

Figure 4:1: Cantabro Loss

4.3.2 Marshall Stability

This test is done to evaluate the sample in the terms of Density, Stiffness and Stability. From Figure 2, 0.2% of Kenaf fibre records the highest value of Density which represent the air voids, since it has high density there are lesser air voids. Thus, making it less susceptible to moisture induced damage and more uniform. From Figure 3, 0.4 % shows the significant value for Stiffness. The equivalent could be said for the Stability at

0.4% Kenaf fibre at Figure 4. Since asphalt constantly exposed to traffic load, it is essential to have a bituminous material which has great solidness.

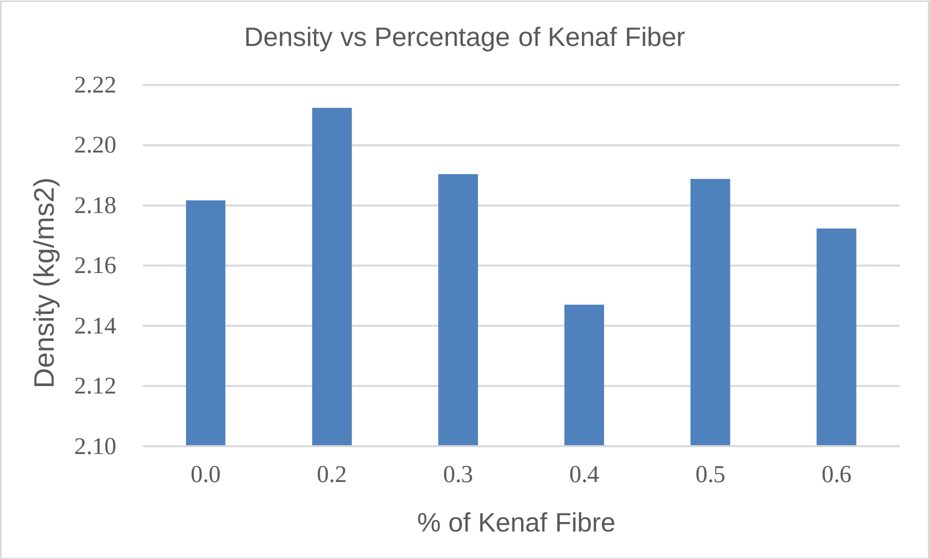

Figure 4:2: Density vs Percentage of Kenaf Fiber

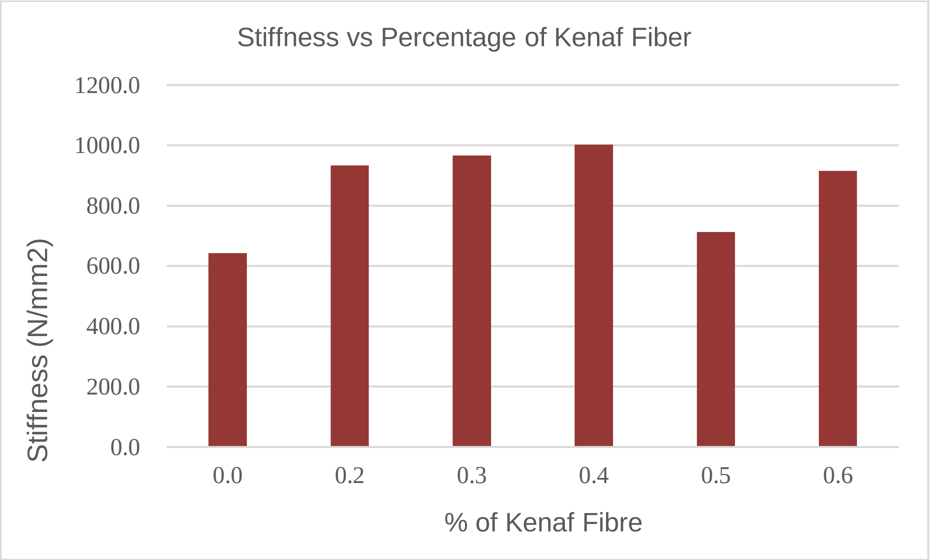

Figure 4:3: Stiffness vs Percentage of Kenaf Fibre

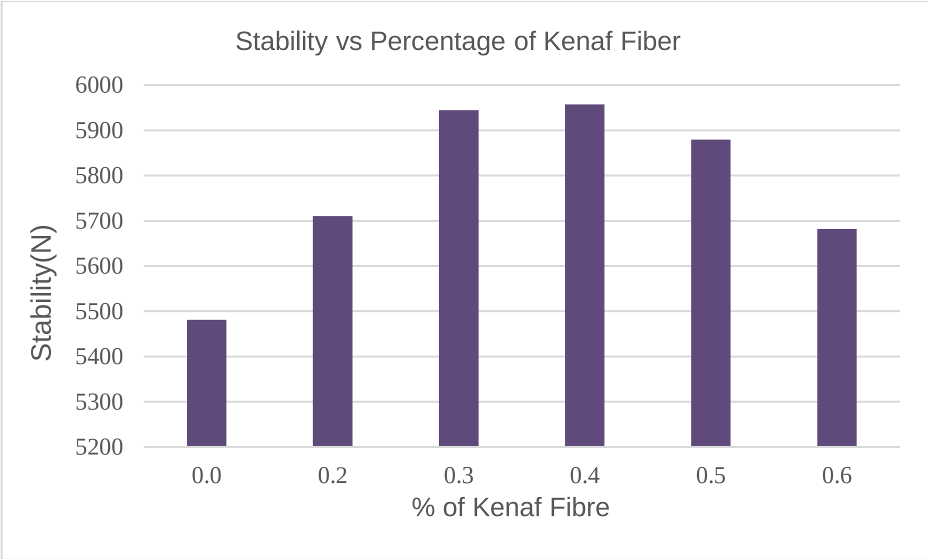

Figure 4:4:Stability vs Percentage of Kenaf Fibre

4.3.3 Resilient Modulus

For the Resilient Modulus test, all the addition of Kenaf fibre shows an increase in the pulse value for the first 1000 except for 0.3%. Then all of them shows a constant reading on the 2000 pulse but when it reaches to 3000 pulse the reading decreases showing Kenaf fibre has low strength when the load is increasing. Overall the reading for 0.6 % shows a great resistance in the strength of the Kenaf fibre when the load is increasing.

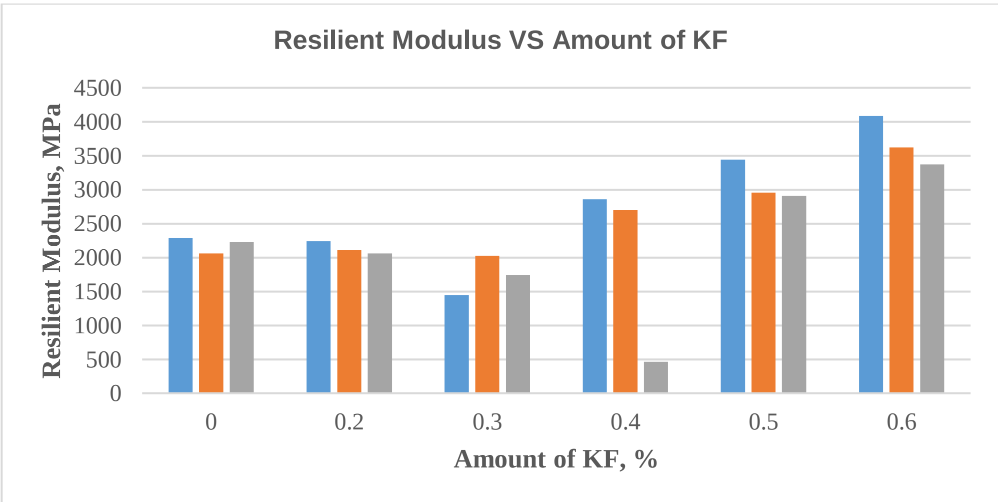

Figure 4:5: Resilient Modulus at 25°C vs Percentage of Kenaf Fibre

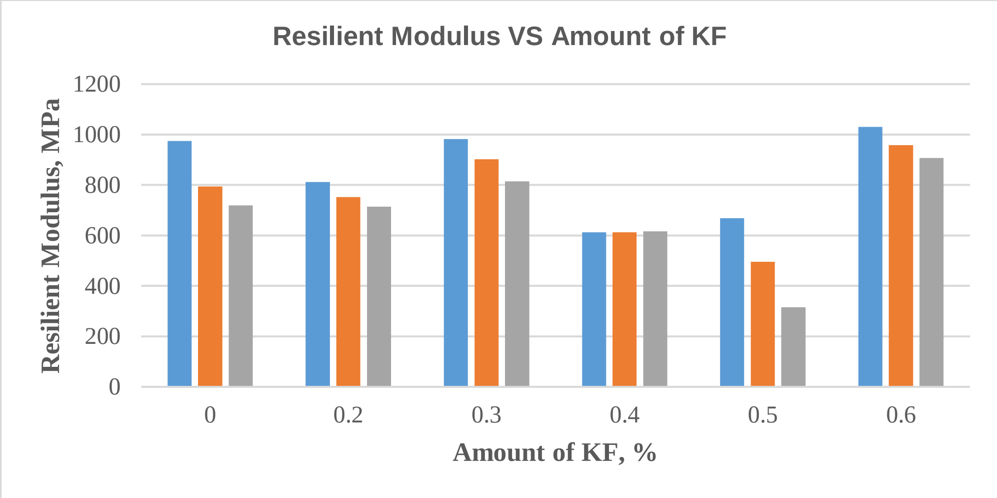

Figure 4:6: Resilient Modulus at 40℃ vs Percentage of Kenaf Fibre

4.3.4 Dynamic Creep

From Figure 4.7, it can be seen that 0% of Kenaf fibre shows the lowest number of permanent strain. In order to access the sample creep behaviour, a control sample is present while testing for other sample with addition of 0.2%, 0.3%, 0.4%, 0.5% and 0.6% of Kenaf fibre. This could be seen that the increasing amount of Kenaf fibre does not influence the strain value of the sample indicating that the resistance against permanent deformation does not influenced by increasing the amount of the fiber.

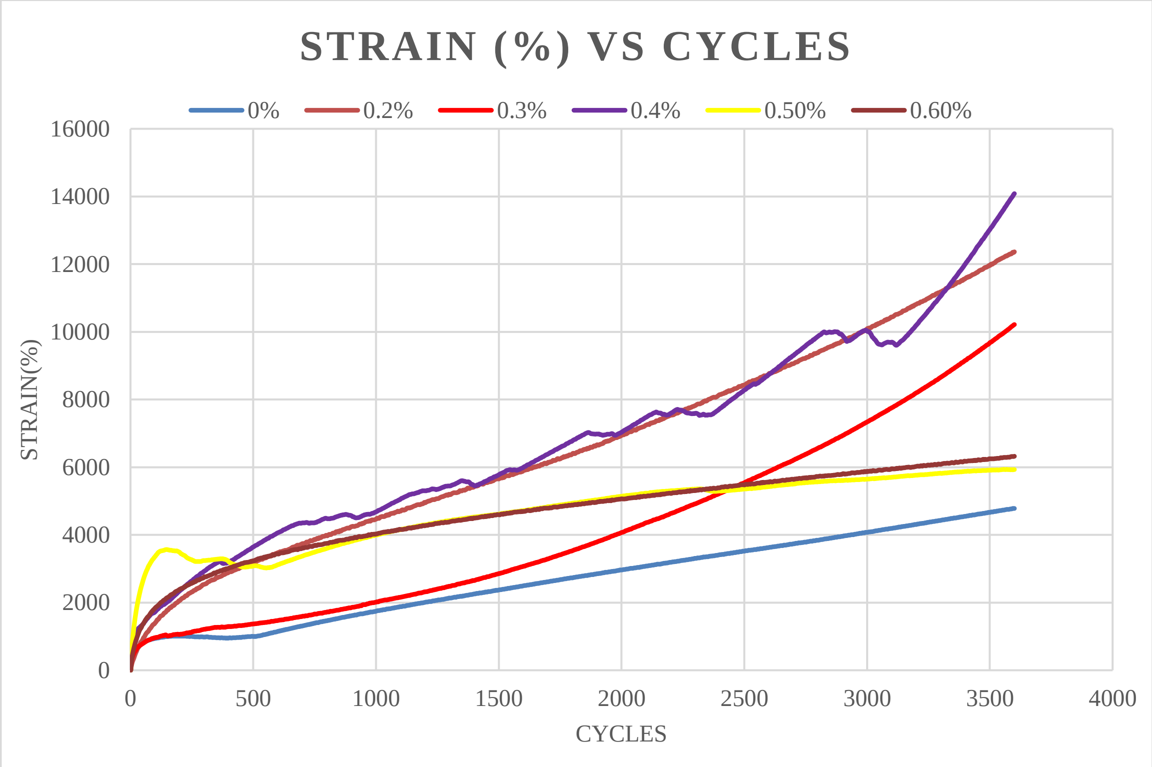

Figure 4:7: Strain (%) vs no of Cycles at 40℃

From Figure 4.8, it can be seen that 0.6% of Kenaf fibre shows the lowest number of permanent strain. Lowest value for permanent strain is good for the permanent deformation such as rutting. It can be seen that by adding more fibre after 0% makes the permanent strain value increases and adding less fibre also does not affect the permanent strain value. Only by adding the optimum content of fibre in the mix could lessen the permanent strain value. From this, the addition of Kenaf fibre could improve the asphalt pavement condition. The strain value shows a more promising improvement in low temperature.

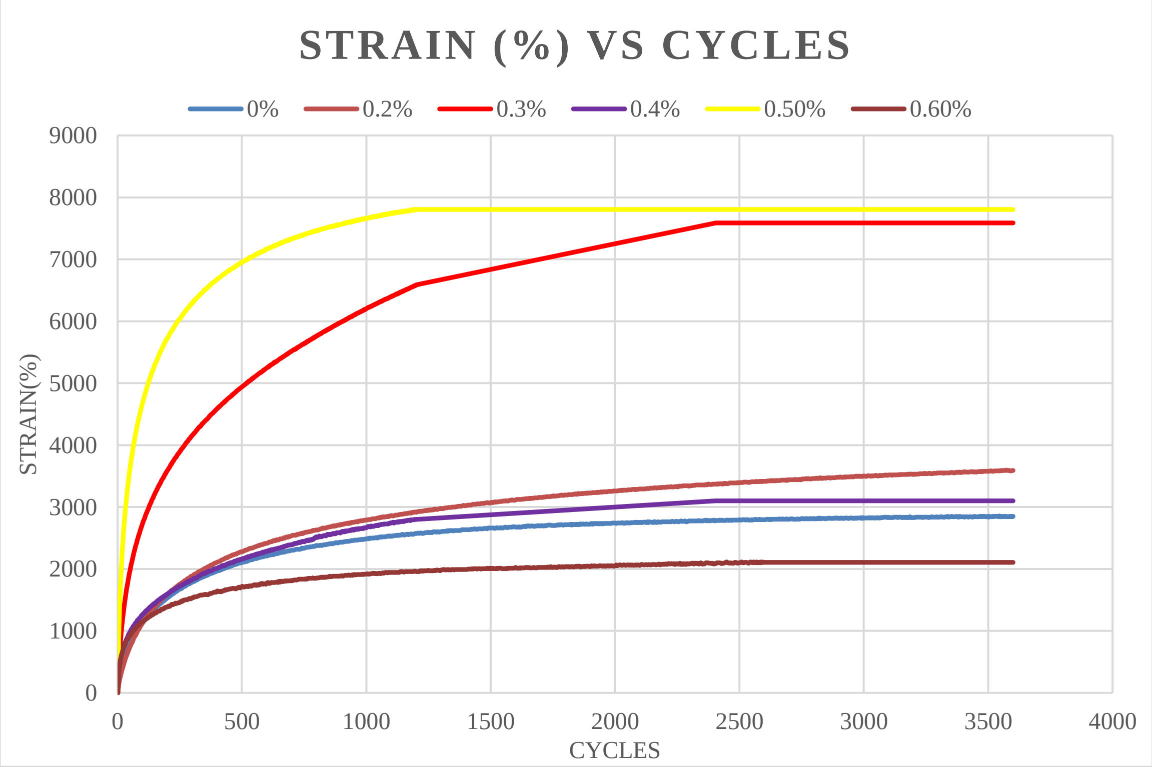

Figure 4:8: Strain (%) vs no of Cycles at 25℃

4.3.5 Optimum Fibre Content

Each performance tests are done with 6 samples each, then they are ranked from number 1 to 6. Number 1 shows the most enhancement which are good while number 6 shows the lowest. The samples are ranked based on each requirement of the performance test and is total up. Lastly, between those 6 values, the lowest value is then decided as the Optimum fibre content. The Optimum fibre Content (OFC) is 0.3 %.

Table 4:8: Ranking of Optimum Fibre Content

Fibre % **Test**	**0**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**
Stiffness	6	3	2	1	5	4
Stability	6	5	2	1	3	4
Density	4	1	2	6	2	5
Resilient Modulus at 25℃	4	5	6	3	2	1
Resilient Modulus at 40℃	3	4	2	6	5	1
Dynamic Creep at 40℃	5	6	2	1	3	4
Cantabro Loss	2	1	3	4	6	5
Total	30	25	19	22	26	24

CHAPTER 5

RESULTS AND DISCUSSION

Introduction

This chapter discusses the conclusion and recommendation based on the results that were obtained in the study.

5.1 Conclusions

Based on the range of Kenaf fibre contents used, and the results of the test conducted, the following conclusion are drawn:

i. 0.2% of Kenaf fibre shows the lowest number on abrasion loss.

ii. From the Marshall Stability test, the stability shows a significant value at 0.4% of Kenaf fibre addition, showing it has less air voids thus, increasing the pavement strength. The stiffness of asphalt increases at 0.4% of Kenaf fibre presence showing that it improves the resistance and low temperature cracking of asphalt. For the density, 0.2% addition of fibre shows the highest density

iii. At temperature 25ºC, results of resilient modulus shows that the highest percentage of Kenaf fibre which is 0.6% gave the highest resilient modulus value. The higher the percentage of Kenaf, the higher the resilient modulus value. Based on the resilient modulus results that were obtained, it shows that the existence of natural fibre such as Kenaf fibre could influence the strength of pavement especially for low traffic. The same could be said for temperature of 40 ºC.

iv. At temperature of 40 ºC, 0% of Kenaf fibre shows the lowest number of permanent strain while for 25ºC, 0.60% addition of Kenaf fibre indicate lower permanent strain. This shows that, at lower temperature, the addition of Kenaf fibre in SMA could contribute in less permanent deformation.

v. From the ranking table of each performance tests, Optimum fibre Content (OFC) is 0.3 %.

5.2 Recommendations

i. Use different type of fiber such as cellulose fiber, steel fiber, coconut fiber, and glass fiber to compare the mechanical properties enhancement.
ii. Use synthetic fibers instead of natural fibers to improve binder performance and reduce water absorption in SMA.
iii. Other than SMA, use different type of mix such as AC14 to compare the characteristic with SMA 20.
iv. For resilient modulus and dynamic creep test, it is recommended to use only one temperature which is 25℃.
v. Additional laboratory tests, such as moisture susceptibility test and wheel tracking test

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APPENDIX A

GRADATION LIMIT OF COMBINED AGGREGATES

ASTM Sieve	Percentage by weight Passing Sieve	
Sieve size (mm)	SMA14	SMA 20
19.0	100	100
12.5	100	85 – 95
9.5	72 - 83	65 – 75
4.75	25 - 38	20 – 28
2.36	16 - 24	16 – 24
0.600	12 - 16	12 – 16
0.300	12 - 15	12 – 15
0.075	8 - 10	8 – 10

APPENDIX B

B.1: STANDARD PENETRATION TEST OF PEN 60/70 AT 25°C

Sample	Penetration Values (PVs)			
	1	2	3	Average (dmm)
A	66	64	65	**65**

APPENDIX C

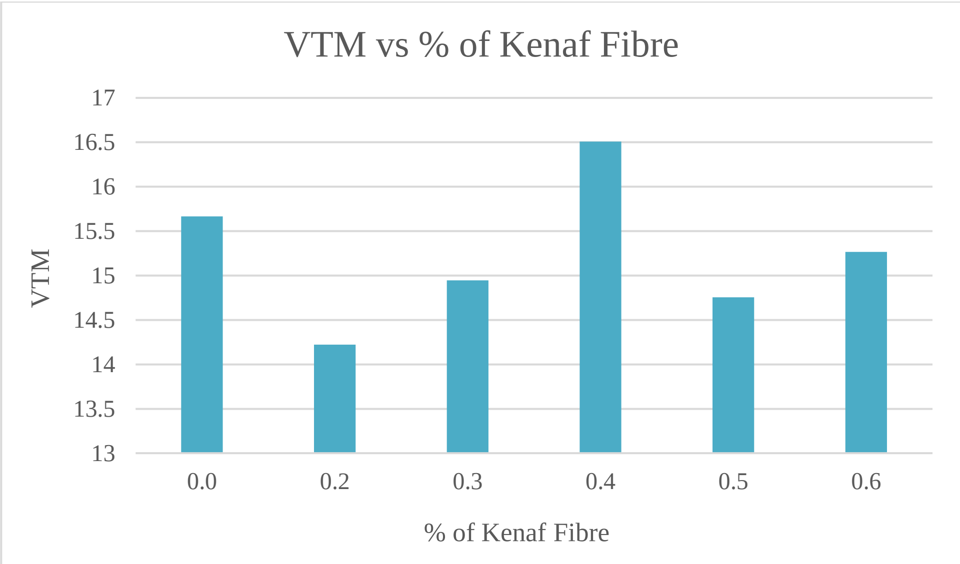
C.1: WEIGHT OF SAMPLE FOR ABRASION LOSS BEFORE AND AFTER

Sample	Fiber Content	Height 1	Height 2	Height 3	Average Height	Weight Before	Weight After 100 repetition	Weight After 200 repetition	Weight After 300 repetition
1	0	76.30	76.32	76.30	76.31	1270.33	1260.36	1253.82	1248.23
2	0	76.32	76.00	75.80	76.04	1270.39	1266.32	1260.54	1254.46
1	0.2	76.73	76.80	76.80	76.78	1270.00	1269.57	1265.56	1263.22
2	0.2	77.21	77.36	77.40	77.32	1273.06	1259.97	1249.62	1243.89
1	0.3	78.62	78.63	78.78	78.68	1283.42	1277.17	1268.73	1264.50
2	0.3	75.20	75.12	75.22	75.18	1279.84	1274.10	1266.11	1256.79
1	0.4	75.02	75.75	74.83	75.20	1259.49	1254.66	1248.38	1241.86
2	0.4	73.64	73.74	73.72	73.70	1250.96	1241.97	1234.85	1227.28
1	0.5	78.00	78.08	78.10	78.06	1290.10	1279.00	1265.46	1256.55
2	0.5	77.09	77.04	77.03	77.05	1293.42	1287.06	1279.58	1271.52
1	0.6	75.30	75.25	75.30	75.28	1277.40	1269.64	1260.77	1253.85
2	0.6	75.82	76.68	75.76	76.09	1278.40	1273.62	1265.57	1257.31

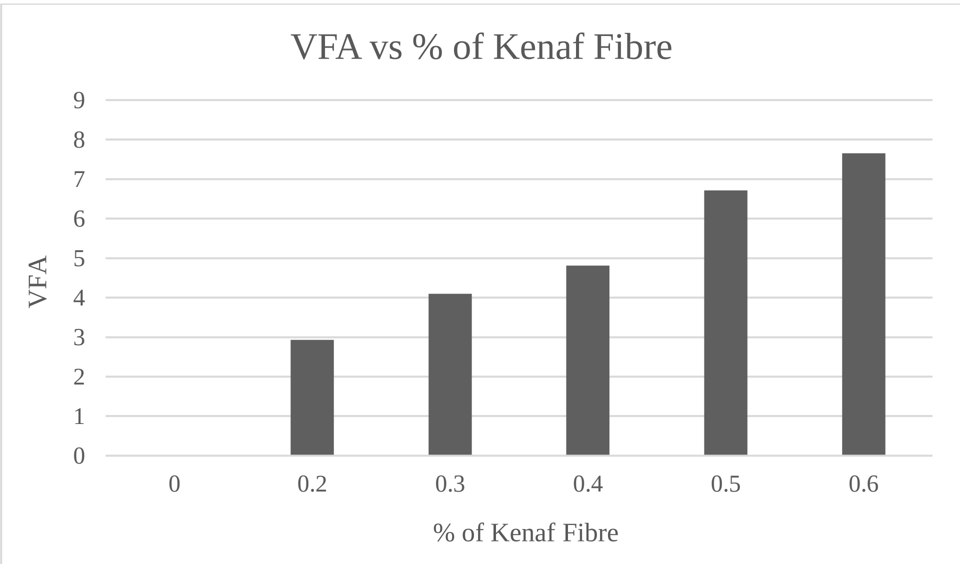
C.2: Abrasion Loss (%)

Fiber Content(%)	Number Revolution		
	100	200	300
0	0.55	1.04	1.50
0.2	0.53	1.10	1.41
0.3	0.47	1.11	1.64
0.4	0.55	1.08	1.65
0.5	0.68	1.49	2.15
0.6	0.49	1.15	1.75

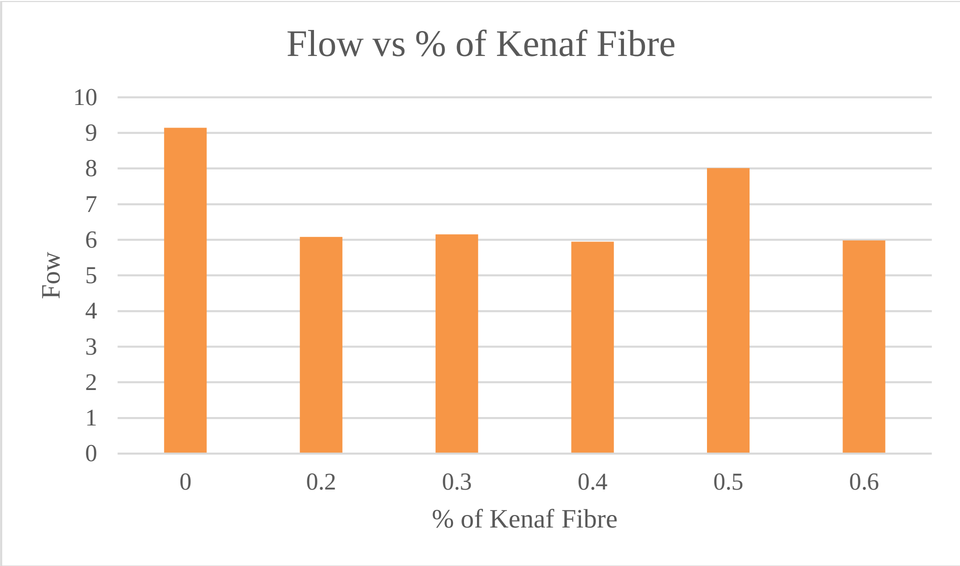
APPENDIX D



D.1 : VTM vs % of Kenaf Fibre



D.2: VFA vs % of Kenaf Fibre



D.3 : Flow vs % of Kenaf Fibre

APPENDIX E

E.1: PERCENTAGE OF KENAF FIBRE VS RESILIENT MODULUS AT 25℃

% KF	Revised Resilient Modulus, Mpa		
	1000	2000	3000
0	2287	2059	2223
0.2	2241	2113	2060
0.3	1447	2028	1746
0.4	2859	2696	464
0.5	3444	2958	2911
0.6	4083	3621	3370

E.2: PERCENTAGE OF KENAF FIBRE VS RESILIENT MODULUS AT 40℃

% KF	Revised Resilient Modulus, Mpa		
	1000	2000	3000
0	975	794	719
0.2	812	752	714
0.3	982	902	815
0.4	613	613	616
0.5	668	496	315
0.6	1031	958	907