# LABORATORY ASSESSMENTS FOR CONVENTIONAL AND FIBER REINFORCED ASPHALT MIXTURES TO ENHANCE PAVEMENT PERFORMANCE

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**SCHOOL OF CIVIL ENGINEERING**

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by

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# ABSTRAK

Pada masa kini, turapan asphalt yang berkualiti adalah sangat diperlukan dan telah menjadi salah satu aspek yang penting dalam prestasi turapan lebuh raya. Turapan yang berkualiti mampu memastikan perjalanan yang lebih selamat dan selesa. Pengubahsuaian bahan pengikat asfalt dan campuran asfalt bertetulang adalah antara inovasi untuk meningkatkan prestasi turapan asfalt. Dalam kajian penyelidikan ini, campuran asfalt yang diperkuat dengan Super Fiber Mix (SFM) dipilih sebagai alternatif untuk penambahbaikan asfalt. Dalam lima dekad yang lalu, penggunaan serat telah di kaji dan digunakan dalam campuran asfalt untuk meningkatkan prestasi turapan di seluruh dunia. Matlamat utama kajian ini adalah untuk mengkaji kesan tambahan serat terhadap prestasi makmal dan membandingkan asfalt yang diubah dengan asfalt konvensional. Laporan ini menggariskan ciri dan sifat asfalt yang diubahsuai yang diadun dengan serat polylrolylene dan aramid. Ujikaji makmal untuk lima ujian utama telah dilakukan dan ujian tersebut *adalah Marshall Stability test, Indirect Tensile Strength test, Resilient Modulus test, Dynamic Creep Modulus test*, dan *Rutting test*. Berdasarkan hasil pengajian, nilai kestabilan Marshall dari sampel asfalt bertetulang meningkat sebanyak 17.8% berbanding dengan campuran konvensional. Nilai *flow* untuk kedua-dua sampel konvensional dan diubah berada dalam julat yang dibenarkan. Walau bagaimanapun, nilai *flow* untuk sampel yang diubah adalah lebih rendah (3.1 mm) berbanding dengan 3.5 mm dari asfalt konvensional, yang menunjukkan bahawa campuran asfalt yang diubah adalah lebih keras. SFM mengandungi serat aramid, yang mempunyai kekuatan tegangan tinggi dan terbukti melalui peningkatan hasil ujian *indirect tensile strength* juga. SFM juga membantu meningkatkan nilai *dynamic creep modulus* sebanyak 24% jika dibandingkan dengan asphalt konvensional. Ujian *dynamic creep modulus* menunjukkan bahawa penggunaan SFM meningkatkan nilai modulus

dan melepasi syarat minimum. Sementara itu, *rut depth* untuk kedua-dua sampel kawalan dan diubahsuai memenuhi syarat minimum 12.5 mm untuk *rut depth* oleh spesifikasi PWD Dalam kes ini, campuran asfalt yang dikuatkan dengan SFM menunjukkan prestasi yang serupa dengan campuran asfalt konvensional.

Secara kesuluruhan, campuran asphalt yang diperkuat dengan SFM menunjukkan sifat kejuruteraa yang lebih baik berbanding dengan campuran asfalt konvensional.

# ABSTRACT

Nowadays, a high-quality and reliable asphalt pavement is desirable and become an important aspect of the highway asphalt pavement performance. A higher-quality pavement can make regular rides safer and more comfortable. Asphalt binder modification and reinforced asphalt mixes are among the innovations to improve asphalt pavement performance. In this research study, asphalt mixture that was reinforced with Super Fiber Mix (SFM) was chosen as an alternative for asphalt pavement improvement. In the past five decades, the use of fibers was investigated and implemented in asphalt mixtures to improve pavement performance worldwide. The primary goal of this study was to examine the effect of additional fiber on laboratory performance and to compare the modified asphalt to conventional asphalt. The report outlines the features and properties of modified asphalt (SFM) blended with polypropylene and aramid fibers. The laboratory assessments for five major tests were conducted and those tests are the Marshall Stability and Flow test, Indirect Tensile Strength test, Resilient Modulus test, Dynamic Creep Modulus test, and the rutting test. Based on the results, the Marshall's stability values of the reinforced asphalt sample improved as much as 17.8% as compared to the conventional mixture. The flow values for both conventional and modified samples are within the allowable range. However, the flow value for the modified sample is lower (3.1 mm) as compared to 3.5 mm of the conventional asphalt, which implies that the modified asphalt mixture was stiffer. The SFM contains aramid fiber, which has high tensile strength and is proven through the increased indirect tensile strength results as well. The SFM also help to increase the Resilient Modulus value by approximately 24%. The dynamic creep test showed that the use of the SFM improved the modulus values and passed the minimum requirement.

Meanwhile, the rut depths for both control and modified samples conform to the minimum requirement of 12 mm for rut depth by the PWD specification. In this case, the asphalt mixture enforced with the SFM exhibits similar performance with the conventional asphalt mixture.

Overall, the asphalt mixture reinforced with the SFM exhibits better engineering properties as compared to the conventional asphalt mixture.

**TABLE OF CONTENT**

## LIST OF FIGURES

## LIST OF TABLES

## LIST OF ABBREVIATIONS

| | |
|---|---|
| ASTM | American Society for Testing and Materials |
| AASHTO | American Association of State Highway and Transportation Official |
| CA | Conventional Asphalt |
| HMA | Hot Mix Asphalt |
| $G_{MB}$ | Bulk Specific Density |
| ITS | Indirect Tensile Strength Test |
| $M_R$ | Resilient Modulus Value |
| MA | Modified Asphalt |
| OBC | Optimum Binder Content |
| SSD | Saturated Surface Dry |
| SFM | Super Fiber Mix |
| VFB | Void Filled with Bitumen |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background of the Study

Asphalt concrete is a composite material consists of bitumen and aggregates which are commonly mixed and used to pave the road surface. About 80% of the roads nationwide are paved and most of the road surfaces are laid with flexible pavement (Sani et al., 2011). Average service life for asphalt pavement could be up to more than 10 years before it reaches the end of its service life and requires significant replacement (Alfalah et al., 2020). The constant load induced by traffic flow causes the tensile and shear stresses in the asphalt concrete to increase, which results in the loss of its structural integrity. As a result, fatigue cracks will develop as the tensile and shear stresses caused by traffic exceeded the pavement material strength limit (Underwood et al., 2014). Thus, the long-term performance of asphalt concrete is negatively affected. The strength of pavement structure will gradually reduce as the asphalt materials continuously degrade (Xuedong et al., 2017)

Apart from the modification of the binder, adding reinforcement in asphalt mixture is one of the strategies used to improve the tensile strength and technical features of the material, especially when the conventional mixture failed to sustain the effect of the repetitive traffic, harsh environmental condition, and degrading pavement structure condition (Bonica et al., 2016). There are various types of reinforcement implemented in asphalt mixtures which includes natural rubber, iron filament, natural fiber, and also synthetic fibers (Xing et al., 2020). However, this research only focuses on the use of synthetic fiber as an additive in asphalt mixture. Since the 1950s, researchers have studied various fibers types into asphalt mixtures to improve the performance.

The application of various synthetic fibers such as nylon, polypropylene, carbon, polyester, and aramid have been evaluated by researchers worldwide. Based on the findings, it was proven that fiber act as an additional reinforcement to the pavement structures and improves the life of the pavement. In 1978, the idea of three-dimension synthetic fiber reinforcement has been proposed to the industrial market worldwide market by Forta Corporation (Ashraf Alrajhi, 2011). One of the inventions is Super Fiber Mix (SFM). The SFM is a high tensile synthetic fiber blend formulated with aramid and polyolefin fibers (AHN VERTEX, 2020). Aramid fiber is known as a fiber that will not melt in the asphalt mix and is also known for its strength and durability in both high and low temperatures.

In Malaysia, AHN VERTEX Sdn. Bhd. is the company that distributes the SFM in Malaysia. There has been an increase in interest in the application of the SFM to flexible asphalt mixtures in recent years. The SFM or also known as FORTA-FI has been studied widely since 1978 and has proven its ability to lengthen the asphalt pavement service life as well as improved the properties of Marshall stability, tensile strength, tensile strength, and resistance to permanent deformation of asphalt (Ashraf Alrajhi, 2011). In recent years, several types of research have been conducted to assess the ability of fiber additives such as nylon, basalt, carbon, a combination of aramid and polyolefin as reinforcement to enhance the asphalt mixtures performance. The addition of the SFM improved tensile strength, Marshall Stability, and resistance to permanent deformation (Alfalah et al., 2020).

## 1.2 Problem Statement

As the world continues to urbanize, the need for quality sustainable pavement becomes a constant demand. Due to this demand, transportation experts and engineers focused on improving the life and performance of pavements (Musa et al., 2019). However, certain locations indicated deteriorated road conditions with surface cracking caused by fatigue, potholes, and rutting caused by the rapidly used and excessive traffic loads from heavy trucks and other vehicles. The deteriorated road conditions with potholes are common for asphalt pavement the ACWC 10 and ACWC 14 gradations provided by the Malaysian Public Work Department (PWD). The reasons could be due to poor mix design, poor road maintenance planning, and poor maintenance job by the appointed contractors. These downsides provide an opportunity to improve asphalt pavement performance using the SFM. In Malaysia, the SFM is not a new material used in road construction projects.

The successful application of this material was under-reported and not well known by the public. The PWD also familiar with this material and has various completed projects that incorporated the SFM in the asphalt mixtures. Therefore, this research was carried out to provide a better understanding of how the use of the SFM in the asphalt mixture improves the engineering properties. Based on the initial review, some of the standard laboratory tests are not available for the SFM produced using the Malaysian PWD ACWC14 gradation. Therefore, the Dynamic Creep test, Indirect Tensile Strength test, Resilient Modulus test, Hamburg Wheel Tracking test of the SFM modified asphalt mixes are needed and carried out through this research.

## 1.3 Objectives

The overall goal of this research is to access the effects of the SFM towards the engineering properties of the asphalt mixture behaviour. To achieve the overall goal of the research, the following research objectives were set:

- To determine Marshall Stability and Flow values, Dynamic Creep Modulus, and rutting resistance of the conventional asphalt and asphalt mixture incorporated with the SFM.
- To evaluate the Indirect Tensile Strength and Resilient Modulus values of the conventional asphalt and asphalt mixture incorporated with the SFM.
- To compare the performance of the modified asphalt mixture with the conventional asphalt mixture (using 60/70 penetration grade binder)

## 1.4 Scope of work

This laboratory assessment focus on the application of the SFM as the reinforcement in the Hot Mix Asphalt (HMA). The HMA was prepared using Malaysian PWD's gradation of ACWC 14 (Nominal Maximum Aggregate Size 14) for wearing course and using 60/70 penetration grade bitumen. Based on the Marshall Mix design approach, the Optimum Binder Content (OBC) was determined at 5.2% for conventional asphalt mix. The Modified asphalt mix with the SFM incorporated similar OBC for mix preparation and test. This laboratory aims to compare the performance between conventional asphalt and modified asphalt whether there is a significant difference in terms of the performance between the two samples.

Four laboratory scale tests were conducted including Marshall Stability Test, Indirect Tensile Strength Test, Resilient Modulus, and the Dynamic Creep Test, Additionally, the samples were tested for resistance against rutting as well. For each test, four samples were prepared consists of two samples with the SFM and two samples without SFM, where the total number of samples are 24 compacted samples. The specification for all the laboratory tests and decision criteria are based on the PWD's specification, JKR/SPJ/2008-S4 for flexible pavement.

## 1.5 Significance of Research

This research highlights how the addition of SFM in asphalt mixture able to improve pavement performance. This research helps the researcher to have a better understanding on the SFM's physical properties and behaviour. Few tests will be carried out such as Marshall Stability and Flow test, Indirect Tensile Strength test, Resilient Modulus test, Dynamic Creep test, and Rutting test. The contribution of SFM will be discovered through the comparison of laboratory tests results between conventional and modified asphalt. Additionally, this research provides knowledge of how the mechanical performance of SFM able to increase the Marshall Stability, rutting resistance, and cracking resistance of asphalt pavement.

Besides, the use of SFM leads to sustainable development as it has a low maintenance cost as well as it prolongs the pavement service life. In addition, SFM is an environmentally friendly material as it recyclable and have less carbon footprint (AHN VERTEX,2020)

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Common Surface Distress of Flexible Asphalt Pavement

This chapter summarizes the findings from previous research related to the use of fiber in asphalt mixtures. The discussion covers a few key performance parameters related to common distresses such as rutting and surface cracking.

Fatigued cracking refers to a dispersed network of interconnecting fracture lines in the pavement as shown in Figure 2.1 below. The worst condition of this type of distress is shown by the alligator cracking. It refers to the linked fissures that resemble the skin of an alligator. Load-related deteriorations initiated due to deficiency in the base course or subgrade strengths, insufficient pavement thickness, traffic overloading, or a combination of these factors, causes fatigue cracking. Generally, repetitive loading and heavy traffic contribute to the structural breakdown of Hot Mix Asphalt (HMA) surface and base layers. In the laboratory, the performance of asphalt pavement in terms of fatigue resistance can be determined by the Indirect Tensile Strength (ITS) test. The study of fatigue cracking behaviour is usually done by the ITS. In 2017, the fracture work density and vertical failure deformation obtained from the ITS were used to determine the resistance of mixtures to bottom-up and top-down cracking (Muftah et al., 2017)

Figure 2.1: Common Fatigue Cracking Occur on Road Surface

Additionally, permanent deformation or also called rutting in asphalt layers is also another common type of asphalt pavement deterioration. This distress type is a substantial impediment to traffic safety, driving comfort, and the entire life cycle of the pavement structure, depending on the level (Miljkovic & Radenberg, 2011). Severe rutting problems jeopardize traffic safety as it accumulates water that can lead to water ponding during the rain. This phenomenon creates a gap between the tyres and road surface. Reduced surface friction between the road surface and tyres caused skidding. Figure 2.2 illustrates how rutting changed pavement surface level.

Permanent deformation of bitumen-aggregate mixes is a complex process whose overall performance is reliant on the aggregate, bitumen, and aggregate-bitumen contact characteristics, among other factors. These qualities (together with their relative effect) fluctuate throughout time, i.e., until the material fails owing to excessive permanent deformation or breaking. The performance of asphalt mixtures is highly dependent on load frequency and temperature, as well as on the voids content. Their flow capability decreases with age, which may play a significant role in the development of irreversible deformity (Miljkovic & Radenberg, 2011). The rutting resistance of an asphaltic mixture can be determined by several laboratory tests which are dynamic modulus, flow number, APA test, and Hamburg Wheel tracking test (Muftah et al., 2017).

Until now, engineers had proposed and came out with multiple approaches to solve these surface distress types. One of the approaches is using fiber in asphalt mixtures. The next sub-chapter describes the early usage of the fiber in pavement construction and previous studies related to the modification. A locally available fiber type named Super Fiber Mix (SFM) is also described in the sub-chapter.

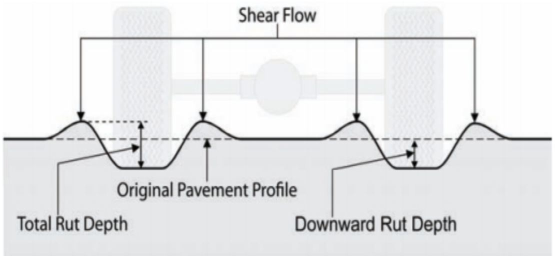


Figure 2.2: The Rutting Deformation (Miljkovic & Radenberg, 2011)

## 2.2 Early Usage of Fiber in Construction

The usage of fiber as reinforcement has been widely implemented since decades ago worldwide. However, the practice of fiber as an additive in asphalt mixtures is not totally a modern technology. The importance of using fiber as the reinforcement started approximately 7000 to 3300 years ago. Where the ancient people of South Asian make used of mudbrick which is the mixture of mud, sand, water, and straw as their construction material for houses. Mudbrick or also called sun-dried mudbrick was the most common construction material employed in ancient Egypt to construct building, statues, and childbirth chair (Falana et al., 2020). In addition, in China there was an arc built using material that was the mixture of the earth clay with fiber approximately 4000 years ago (Hongu et al., 1990 and Musa et al., 2019).

However, the incorporation of fiber in asphalt as reinforcement started approximately in the 1950s. The idea of adding various types of synthetic fiber involving polyester, nylon, polypropylene, and carbon to act as reinforcement in order enhance to enhance asphalt performance (Abtahi et al., 2010). Nowadays demand for supremacy asphalt continuously soaring upwards which indirectly enforced the researcher to make several research studies to deal with the damage and finding ways to prolong the service life of asphalt pavement (Rajeshwar, 2017). The use of fiber as an additive is still relevant and there are opportunities everywhere as the industrial players keen to promote the use of the fiber into a larger-scale implementation, considering the potential of the additive to prolong asphalt pavement service life.

## 2.3 General Studies that Incorporate Fiber as an Additive

Fiber reinforcement was employed as both a crack barrier and a reinforcing element, with the purpose of carrying tensile loads and preventing crack formation and propagation (Shukla et al., 2015). There are two major types of fibers which are natural and synthetics fibers. In the sub-chapters below, a few types of synthetic fibers such as polyester, carbon, and Forta-Fi fibers will be further discussed based on the previous research studies.

### 2.3.1 Polyester Fiber

Polyester is a polymerized product of crude oil materials. The application of polyester is usually involved when a strong and long-lasting reinforcement of bitumen-fiber mastics is needed at high temperatures. In 2008, Perviz Ahmefzade and Mehmet Yilmaz studied the influence of polyester fiber on the physical and mechanical properties of asphalt binders and mixtures. The penetration and softening point data of asphalt with 0.75% polyester binder demonstrated the increased stiffness and able to improve the temperature susceptibility compared to the control sample.

Based on test results for fatigue properties and rheological characteristics, the implementation of polyester fiber indicated that the viscosity of asphalt binder increased with the increase of polyester fiber content, especially at lower temperatures and lower stress levels (Ahmedzade & Yilmaz, 2008). Other researchers investigated the impacts of fibers on the percent voids in mineral aggregate (VMA) in asphalt concrete using the HMA mixture of four different fibers namely flocculent lignin fiber, mineral fiber, polyester fiber, and blended fiber. As compared to the standard HMA blend with lignin fiber, the polyester fiber, and natural fiber had a big impact on volumetric properties, resulting in better VMA (Ahmedzade & Yilmaz, 2008).

A group of scientists from the Central Road Research Institute (CRRI) in New Delhi investigated the behaviour of polyester and glass fiber in asphalt mixtures in 2015. The laboratory assessment was carried out by applying 0.15% of glass fiber and 0.2% of polyester fiber. Several tests were carried out, such as resilient modulus, dynamic modulus test, indirect tensile test, flexural beam fatigue test, and skid resistance test. The Marshall test, result shows that the OBC of the modified asphalt mix increased by 0.02% and 0.05% respectively, which explains that asphalt mixes incorporating fiber require slightly more bitumen content for coating. Besides, results of the Marshall stability test of modified asphalt shown that the presence of fibers improve the Marshall stability value up to 10% to 13% (Shukla et al., 2015)

Additionally, the modified asphalt can improve indirect tensile strength and resilient modulus by up to 25% and 38%, respectively. The fatigue life cycles of polyester and glass fiber asphalt mixture at 25 C shown significant improvement of 40% and 29%. The ability of polyester and glass fiber to improve rutting resistance and skid resistance is also undeniable, with polyester fiber modified asphalt improving rutting resistance by 21% and skid resistance by 11%. Based on all the test results, it was proven that the addition of polyester as glass fiber was able to improve the performance of asphalt pavement (Shukla et al., 2015)

### 2.3.2 Carbon Fiber

The carbon fiber, also known as graphite fiber, is a solid, stiff, lightweight material that able to replace steel in high-performance items such as aircraft, race cars, and sporting equipment. Because of its strength, researchers decided to consider carbon fiber in their quest for high-quality road pavement. An experimental study on the effect of glass and carbon fiber was conducted by Majid Alidadi and Mohammad Mehdi Khabiri in the year 2016. This research studied the effect of various fiber contents used in the modified asphalt mixtures.

Based on the findings, the presence of fibers able to reduce the fracture energy with an improvement in the external tensile strength of the fibers. Furthermore, the indirect tensile strength of the modified asphalt was increased because of the improved cohesion of the asphalt mixture. The crack propagation of asphalt pavement is prevented by the presence of fiber as a great bond connector between the aggregate and bitumen (Alidadi & Khabiri, 2016).

Other research conducted in 2019 revealed that the addition of carbon fiber showed an improvement in Marshall properties and stability value of asphalt mixture (Mawat & Ismael, 2020). Three different lengths of the carbon fiber were used which are 1.0 cm, 2.0 cm, and 3.0 cm. Based on the result, higher stability recognizes for a specimen containing 2.0 cm long fiber values compared to 1.0 cm and 3.0 cm. The researcher concluded that having a good physical property of fiber is essentials to produce a good asphalt mixture that performs well at the site.

### 2.3.3 SFM by Forta Corporation

In 1978, Forta Corporation in the United States of America (USA) started to focus on the future of pavement materials and on inventing a type of synthetic fiber called Forta-Fi (E.Kaloush et al., 2010). It is a high tensile synthetic fiber blend formulated with polyolefin and aramid fibers. Both fibers have their own favourable characteristics that yield different results when utilized in HMA (Ashraf Alrajhi, 2011). Table 2.1 presents the physical properties of the Forta-fi fibers used by Forta Corporation and the AHN VERTEX company.

Table 2.1: The Physical Properties of SFM fibers (AHN VERTEX Brochure)

| **Physical Properties** | **Aramid Fibers** | **Polyolefin Fibers** |
|---|---|---|
| Length (mm) | 19 | 19 |
| Form | Monofilament | Serrated |
| Acid/Alkali Resistance | Inert | Inert |
| Tensile Strength | 2758 MPa | N/A |
| Specific Gravity | 1.44 | 0.19 |
| Operating Temperature (˚C) | -73 to 427 | N/A |

The most important types of polyolefins are polypropylene and polyethylene. The polypropylene fiber is chemically inert and is non-corrosive and non-absorbent. The polyolefin fiber has a lower melting point compared to the aramid fiber and will melt at a certain temperature limit during the blending process. As for aramid fiber, it has high tensile strength and high-temperature resistance up to 427 C while remaining non-corrosive. This Forta-Fi fiber will be addressed as the SFM throughout the report chapter. This fiber was selected as the additive in this research based on the availability of the materials due to ongoing demand by the PWD and non-government agencies to incorporate the SFM in asphalt mixtures. Figures 2.3 a and b show the original form of the aramid and polyolefin fibers.

Figure 2.3 (a): Aramid Fibers

Figure 2.3 (b): Polyolefin Fibers

Figure 2.3 (a)(b): The Original Form of The Aramid and the Polyolefin Fibers

In Malaysia, scores of milling and paving projects had their fiber in the modified asphalt mixtures supplied by the AHN VERTEX Sdn. Bhd. company. This company was the country's first SFM distributor. Their products had covered almost all the states in Malaysia as they also collaborated with JKR Malaysia to counter the repair of road work in this country. The SFM was selected due to its benefit. Besides the ability to increase the strength and durability of the pavement, the SFM fiber also has other advantages such most cost-effective option for asphalt maintenance, easy to mix, and environmentally friendly as they are recyclable. One of their latest projects was the maintenance milling and paving of road surface work located at Jalan Alor Setar – Butterworth in Jun 2021 (AHN VERTEX, 2020).

## 2.4 A previous study on the Forta- Fi (SFM) in asphalt mixtures

In 2010, researchers at the Arizona State University studied sixteen different combinations of the SFM percentages consist of polypropylene and aramid fibers. The research aimed to find the best material configuration to optimize the performance of the SFM. The result indicated that the best viscosity performance came from the combination of three dosages of polypropylene and one dosage of aramid. It was able to promote the highest viscosity and the lowest VTS value indicating a lesser temperature susceptibility to both permanent deformation and thermal cracking. As for dynamic modulus, it increased by the increasing amount of fibers as compared to the control sample (E.Kaloush et al., 2010).

In 2016, Fouad Bayomy and Ahmed Muftah of Idaho University are taking part in the Idaho Transportation Department (ITD) project to improve the road section that experienced severe cracking and rutting due to heavy truckloads. Three types of fibers were used in this project, which was the blend of polypropylene with aramid fibers, waxed aramid fibers, and glass fibers. The asphalt pavement parameters such as cutting resistance, fatigue cracking resistance, and low temperature thermal cracking resistance were all tested in the lab in order to study the effectiveness of all three types of fibers. The dynamic modulus and flow number test, the APA test, and the Hamburg wheel test are all used to determine rutting resistance.

In this research, the value of dynamic modulus is used as an input to the Mechanistic-Empirical Pavement Design Guide (MEPDG) program to predict the performance of the specimens. The dynamic modulus test was conducted at the following temperatures: 40°F, 70°F, 100°F, and 130°F. Six different loading frequencies were employed at each temperature: 25, 10, 5, 1, 0.5, and 0.1 Hz. Based on the test results, the dynamic modulus master curves demonstrated that at the high frequency (or low temperature) level where the dynamic modulus is not affected by asphalt binder fluctuation, the dynamic modulus values of all the fiber mixtures were comparable. The highest dynamic modulus value resulted from the Forta-fi fiber at temperatures of 70˚F and 100˚F.

However, when all the results are compared, there is no statistically significant difference between the mixed performance at low and high temperatures. Thus, they conclude that fibers may not be able to give significant improvement to mix performance at low and high temperatures. The other test for low thermal cracking resistance and fatigue cracking resistance also showed undesirable results which the reinforced asphalt with Forta-fi fibers does not give significant improvement to the asphalt performance. As for recommendations for future study, they stated that more investigation is needed to be done by having more mixtures with a variety of fiber ratios (Bayomy et al., 2016). In the same year, Alidadi & Kabiri studied the importance for fiber content in asphalt mixture. From the study, it was observed that too low fiber content increase the tendency of weak cross-section, leads to crack propagation on surface. Meanwhile, an excessive fiber content may reduce the aggregate cohesion and cause all fiber shrink in one location.

A similar conclusion was made in the year 2018, a study about the effects of the Forta-Fi fibers on the dynamic, modulus rutting potential, flow number, and fatigue of asphalt concrete done by Elbert Rohrbough from West Virginia University. In this research, all the tests were conducted using the Asphalt Pavement Analyzer (APA) and the Asphalt Mixture Performance Tester (AMPT). In this project, two samples are being analyzed: a control sample and a reinforced sample reinforced with Forta-Fi fibers. The dynamic modulus, flow number, and fatigue properties of the two mixes were determined using the AMPT. While the APA was used to determine the rutting propensity of the two mixes. Initially, the results of the APA rutting test indicated that the overall average rut depths of the two combination types were relatively similar. The T-test was used to determine whether there was a significant difference in the average rut depths of the two mixtures based on the combined APA data. The t-test revealed inadequate evidence to support the performance of Forta-fi fiber, and at a 95% confidence level, no significant difference in the average rut depths of standard and modified asphalt mixes can be established (Rohrbough et al., 2018).

As for dynamic modulus and phase angle, the analysis shows quite a similar result between conventional and modified samples. At the end of the research, Elbert Rohrbough also states that the implementation of Forta fiber does not provide a significant improvement. A further study, using different ratios of Forta usage in the mixture, was desirable for future study. (Rohrbough et al., 2018). In 2019, Musa et al studied on the most suitable mixing method for dispersing fiber. There are two type of mixing method which are dry and wet method. Stated that the dry method is more favourable as it provides a better dispersion and uniformity for fiber modified method.

## 2.5 Fiber Mixing Method

Generally, the wet process and the dry process are the two most popular mixing methods for uniformly dispersing fiber in asphalt mixtures (Musa et al., 2019). The fibers are blended with asphalt before the binder is added in the wet mix phase, while the fiber and aggregate are blended before the asphalt is added in the dry-mix process. In practice, dry mixing is usually more favourable due to processing issues such as clumping or balling of fiber in the mixture. The advantages of using the dry mixing method can provide better dispersion and uniformity placement of fiber during the mixing process. Aside from its ability to reduce some major issues such as balling or clumping of fibers in asphalt mix, the dry mix method is much easier to carry out as it is normally used in fieldwork (Abtahi et al., 2010). However, adhesion between binder and aggregates tends to occur for some fibers that will melt in hot aggregates. This concludes that for some fibers that has a lower temperature resistance, the dry mix method is not convenient to use during the mixing process. As for the wet mixing method, it is appropriately used in a type of plastics fiber with melting points below 160°C, such as low-density polypropylene (PP), high-density polyethylene (HDPE), and polyethylene (LDPE). One of the disadvantages is the tendency of fiber sticking to each other is high during the mixing process. Figure 2.4 (a) (b) show the applied method of wet and dry mix. However, researchers in some studies have also modified the way of mixing to observe a better dispersion of the fiber.

Back in 2014, Zahedi et al has studied the most suitable way of mixing polypropylene fibers with the mix design. In this study, the researchers have implemented a complex mixing method since the dry and wet mixing method does not achieve a homogenous mixture. In this method, the fibers were successfully blended and produced a homogeneous mixture by mixing the aggregates and bitumen in a mixer for 5 to 10 seconds before segregating the fibers gradually into the mixture (Zahedi et al., 2014). As a result, it is reported that a complex method is an ideal method for designing and carrying out experiments for their research.

(a) Wet Process(Mawat & Ismael, 2020) (b) Dry Process

Figure 2.4 (a) (b): The types of fiber mixing methods in asphalt production.

## 2.6 Summary

In this chapter, the use of synthetic fibers were discussed based on the previous studies. Over five decades ago, the innovation of incorporating fiber (both natural and synthetic fiber) as reinforcement in asphalt pavement began. The types of synthetic fiber used include polyester, carbon, aramid, polyolefin, the combination of aramid and polyolefin (SFM), and many more. Research on the SFM has been highlighted as it is the type of fiber used in this research. In 1978, Forta Corporation in the US started to focus on the future of pavement materials and on inventing a type of synthetic fiber called Forta-Fi. Many researchers around the world are investigating the impact of SFM contribution on asphalt pavement. In previous studies, some researchers claimed that incorporating SFM into the asphalt mixture improved the pavement's performance significantly. However, in some studies, the results did not show a significant improvement, and researchers were advised to conduct additional laboratory testing. A fiber content that is either too low or too high will not improve the asphalt pavement. An adequate amount of fiber is desirable. There are two types of mixing methods used in producing fiber-modified asphalt, which are the dry method and the wet method. Fiber with a low melting point is advisable to use a wet mixing method as the adhesion between the binder and the aggregates tends to occur for some fibers that will melt in the hot aggregates. Most researchers used the dry mixing method because it provides better dispersion during the mixing process. This dry method of mixing was adopted in this research as well.

# CHAPTER 3

# METHODOLOGY

## 3.1 Overview

In this chapter, the methodology for all laboratory tests were described in detail. Figure 3.1 illustrates the flow of this research study. These laboratory assessments were carried out after gathering the information from the previous research studies. The asphalt binder was subjected to a few basic tests to study the physical properties including penetration test, flash and fire point test, ductility test, and ring and ball tests. The selected aggregate gradation for the conventional and modified asphalt was batched according to PWD’s ACWC 14 gradation. The supplied SFM with the ratio of 0.05% of the total mixture used according to the supplier recommendation. Later, the mixing and compaction procedure were conducted for all the asphalt mixes. The determination of the OBC was done to get the most suitable amount of bitumen content before the mixing process.

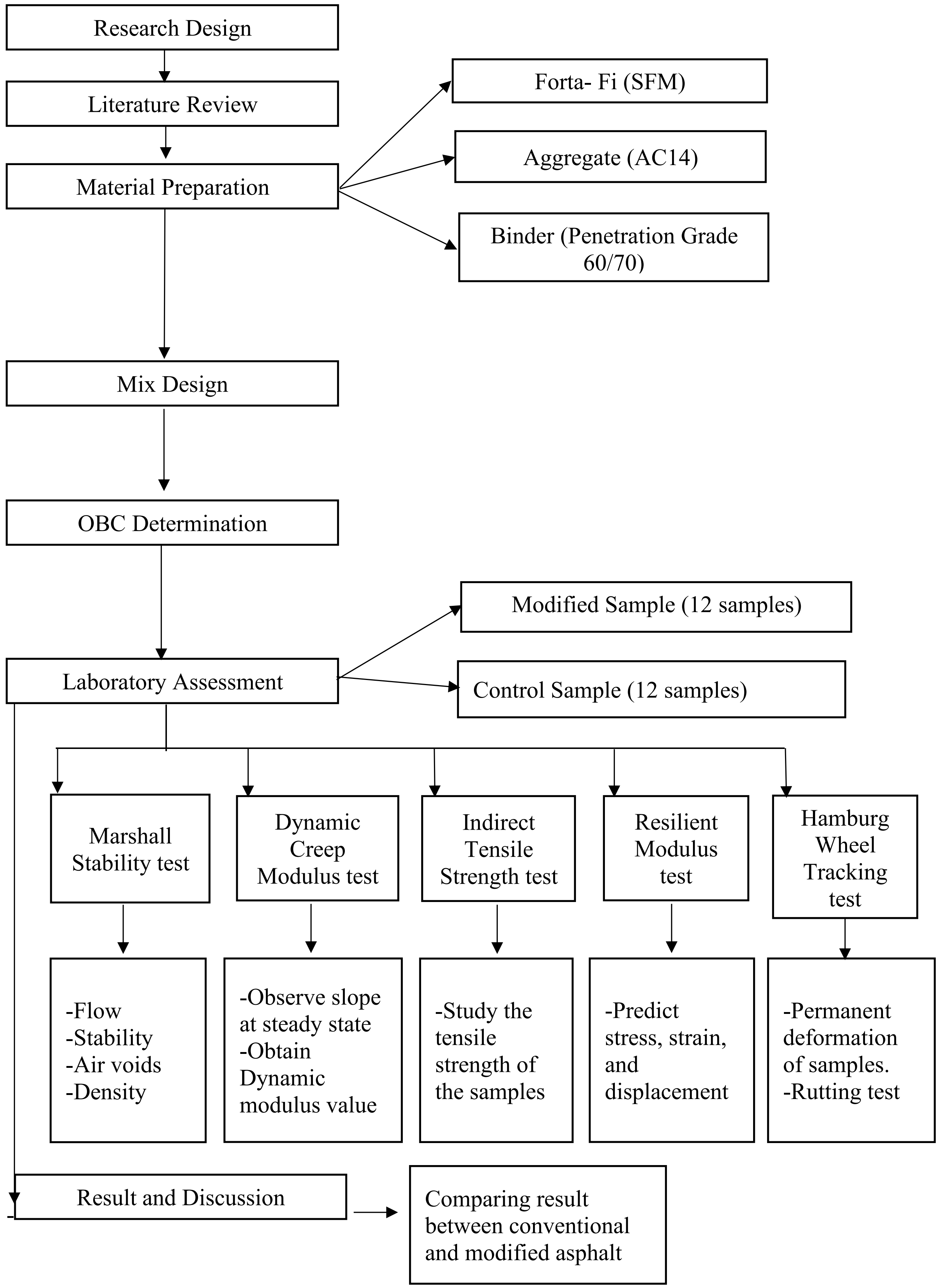


Figure 3.1: The Flowchart of the Study.

## 3.2 Laboratory Specimens

All samples prepared in this study were conducted in USM's Highway Laboratory located at Nibong Tebal, Penang, Malaysia. Briefly, the first step to prepare the asphalt mixture is to select a mix design. Then, prepare and batch aggregates per mix design before heating the aggregates and bitumen. The aggregates are heated in the oven for four hours, and one hour for bitumen so that it liquefies. The aggregate and bitumen are blended until all the aggregates are coated with bitumen. The fiber is added during the mixing process.

### 3.2.1 Mix Design of Aggregates and Binder Content

Granite aggregates were provided by the Civil Engineering School, USM. A combination of various sizes of aggregates according to sieve size by JKR with a cumulative mass of 1150g which was the standard aggregate portion of laboratory sample with 100 mm diameter and 63.5 mm height. For the conventional sample, the ACWC14 gradation was prepared one by one for eight batches of samples. The gradation for ACWC14 with sizes ranging from 14mm, 10mm, 5mm, 3.5mm, 1.18mm, 425µm, 150µm, 75µm, mineral filler, and hydrated lime was prepared by weighing each size of aggregate based on the required percentages and placed in a plastic bag.

Hydrated lime is used as an anti-stripping agent which stiffing the HMA and asphalt binder. It improves moisture stability and longevity by alternating the plastic properties of clay fines. As for asphalt mixture modified with the SFM (also mentioned as reinforced samples), the aggregates mix design was prepared with a cumulative mass of 10 kilograms (kg) to ease the process of batching afterward according to the standards procedure given by the supplier. Tables 3.1 and 3.2 represent the mix design used to prepare the sample. As for the binder content, 5.2% BC was used based on the Optimum Binder Content (OBC) determined from the laboratory test for unmodified samples. Equation 3.1 is used to determine the percentage of binder content needed for a particular mass of aggregates.

$$Binder\ Content\ (BC, g) = \frac{BC(\%)}{100 - BC(\%)} \times Mass\ of\ aggregate(g) \ \ldots\ldots \text{ Equation 3.1}$$

Table 3.1 shows the designed aggregates mix of conventional asphalt design for one sample. Meanwhile, Table 3.2 shows the aggregates mix design for modified asphalt for the 10kg batching sample. This is because of the SFM content given by the supplier determined for 10kg batching preparation.

Table 3.1: Mix design of AC14 for the conventional mix.

| B.S Sieve Size (mm) | Design (%) | Mass of aggregates (g) | The cumulative mass of Aggregates (g) |
|---|---|---|---|
| 14 | 5 | 57.5 | 57.5 |
| 10 | 14 | 161.0 | 218.5 |
| 5 | 25 | 287.5 | 506.0 |
| 3.35 | 9 | 103.5 | 609.5 |
| 1.18 | 21 | 241.5 | 851.0 |
| 425µm | 8 | 92.0 | 943 |
| 150µm | 8 | 92.0 | 1035 |
| 75µm | 4 | 46.0 | 1081 |
| Mineral Filler | 4 | 46.0 | 1127 |
| Lime Filler | 2 | 23.0 | 1150 |

Table 3.2: Mix design of AC14 for the modified mix.

| B.S Sieve Size (mm) | Design (%) | Mass of aggregates (g) | The cumulative mass of Aggregates (g) |
|---|---|---|---|
| 14 | 5 | 500 | 500 |
| 10 | 14 | 1400 | 1900 |
| 5 | 25 | 2500 | 4400 |
| 3.35 | 9 | 900 | 5300 |
| 1.18 | 21 | 2100 | 7400 |
| 425µm | 8 | 800 | 8200 |
| 150µm | 8 | 800 | 9000 |
| 75µm | 4 | 400 | 9400 |
| Mineral Filler | 4 | 400 | 9800 |
| Lime Filler | 2 | 200 | 10000 |

### 3.2.2 The Physical Properties of Aggregate and Bitumen

A few tests on aggregates such as the Specific Gravity Test, Los Angeles Abrasion Test (LAAV), and Flakiness and Elongation Index Test, are usually carried out to ensure the physical properties of aggregates used in the asphaltic mixture comply with the standard. Table 3.3 shows the physical properties of bitumen and aggregate by Hasan Ziari in the year 2020. The Specific Gravity Test is a measure of material density by measuring the amount of water absorbed into the pore structure. The LAAV test was conducted to determine the hardness of aggregates and to evaluate the resistance of the aggregate against abrasion and mechanical degradation during handling, construction, and use. Flakiness and elongation index test was carried out to study the strength of aggregates based on their shape.

As for bitumen characterization, the common tests to be carried out were penetration test, ductility test, ring and ball test, and flash point test. The ring and ball test is to determine the softening point of bituminous material. Ductility test determined the properties of the bitumen which allow it to be stretched to a certain length without causing any rupture. The flashpoint test serves as a purpose as a safety precaution. This is to prevent the danger of fire during the heating process of the bituminous materials. Due to limited time to conduct laboratory tests, the following bitumen and aggregate engineering properties were selected and included in this report. The specific gravity (SG) for bitumen is slightly lower as compared to the SG of 1.03 for bitumen in Malaysia.

Table 3.3: Physical Properties of Bitumen and Aggregates used in this research (Ziari et al., 2020)

| Test | Unit | Standard | Results |
|---|---|---|---|
| **Bitumen Test Result** | | | |
| Viscosity Test at 135˚C | cSt | ASTM D113 | 362 |
| Penetration Test | mm | ASTM D5 | 64 |
| Ductility Test | cm | ASTM D113 | 100 |
| Softening Point | ˚C | ASTM D36 | 50 |
| Flash Point | ˚C | ASTM D92 | 295 |
| Specific Gravity | $g/m^3$ | ASTM D70 | 1.017 |
| **Aggregate Test Result** | | | |
| Coarse Aggregate Specific Gravity | $g/m^3$ | ASTM D127 | 2.55 |
| Fine Aggregate Specific Gravity | $g/m^3$ | ASTM D128 | 2.54 |
| Los Angeles Abrasion Value | % | ASTM D131 | 20.1 |
| Sodium Sulfate Soundness | % | ASTM D88 | 2.50 |
| Sand Equivalent | % | ASTM T176 | 67.0 |
| Flakiness | % | BS-812 | 15.42 |

### 3.2.3 Fiber ratio

In preparing fiber reinforced asphalt, the amount of fiber selected is very important. An appropriate amount of fiber which is 0.05% from the total mix used based on the recommendation of the supplier. Selecting the appropriate amount of fiber content in asphalt mixtures is important. Too high or too low amount of fiber will not give a good effect in terms of performance. Low fiber content may increase the