ASSESSING THE EFFECTS OF POLYOLEFIN FIBER ON THE PROPERTIES OF MODIFIED ASPHALT BINDER

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By

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway Transportation Officials
APAO	Amorphous Poly Alpha Olefin
ASTM	American Society for Testing and Materials
DSR	Dynamic Shear Rheometer
MSCR	Multiple Stress Creep Recovery
PAV	Pressure Aging Vessel
PE	Polyethylene
PET	Polyethylene Terephthalate
PG	Performance Grade
PP	Polypropylene
PS	Polystyrene
POC	Polyolefin Composites
RTFOT	Rolling Thin Film Oven Test
RV	Rotational Viscosity
SBS	Styrene Butadiene Styrene triblock
SFM	Super Fiber Mix
STA	Short-term aging
TFOT	Thin Film Oven Test

MENILAI KESAN SERAT POLYOLEFIN TERHADAP SIFAT-SIFAT PENGIKAT ASFALT YANG DIUBAI SUAI

ABSTRAK

Dalam beberapa tahun kebelakangan ini, pengubahsuaian pengikat asfalt telah menjadi popular dalam pembinaan turapan asfalt. Dari masa ke masa, apabila jumlah lalu lintas dan beban meningkat, pengikat asfalt merosot dan akhirnya tidak dapat menampung beban, sekali gus merosakkan jalan raya. Penambahan tetulang gentian polimer dan kaedah lain untuk pengubahsuaian asfalt adalah kaedah penyelidikan yang berpotensi mengatasi masalah ini. Oleh itu, kaedah ujian dalam menentukan sifat fizikal dan reologi pengikat asfalt diubah suai dan pengikat konvensional adalah penting untuk meningkatkan prestasi bekas dan kelakuan elastik pengikat asfalt. Kajian ini dijalankan bagi menilai kesan penambahan poliolefin ke dalam pengikat yang tidak terusia dan berusia. Ujian makmal yang dipertimbangkan ialah penusukan, kemuluran, takat lembut, takat kilat, pemulihan elastik, dan pemulihan kilasan dan ujian reologi. 0.05% daripada jumlah berat pengikat diubah suai polimer dan didapati dapat meningkatkan rintangan beban dan meningkatkan kelikatan pengikat asfalt, tetapi prestasi elastik bahan pengikat yang diubah suai telah berubah secara tidak ketara berbanding dengan pengikat asfalt konvensional. Selain itu, prestasi rintangan merekah selepas jangka masa panjang berkurangan kerana elastic bahan selepas penambahan poliolefin telah berubah secara tidak ketara. Kajian lanjut adalah perlu untuk menilai bagaimana susunan molekul poliolefin berubah semasa proses penuaan sejak kekerasan dan elastik pengikat asfalt diubah suai diubah selepas penuaan jangka pendek. Kajian ini membantu untuk memahami sebab di sebalik perubahan dan bagaimana ia memberi kesan kepada kekerasan pengikat secara terperinci.

ASSESSING THE EFFECTS OF POLYOLEFIN FIBER ON THE PROPERTIES OF MODIFIED ASPHALT BINDER

ABSTRACT

In recent years, the modification of asphalt binders has become popular in asphalt pavement construction. Over time, as the traffic volumes and loads increase, the asphalt binder degrades and eventually unable to resist and endure the loads, thus damaging the roads. The addition of polymer fiber reinforcement and other methods for modification of asphalt are promising research methods to overcome these problems. Therefore, a test method in determining the physical and rheological properties of modified asphalt binder and conventional binder is crucial to improve the rutting performance and elastic behavior of asphalt binder. This study investigates the effects of polyolefin on the unaged and aged polymer-modified binders. The laboratory tests considered are penetration, ductility, softening point, flash point, elastic recovery, and torsional recovery and rheological test. The 0.05% from the total weight of polymer-modified binder has been found to improve the rutting resistance and increase the viscosity of the asphalt binder, but the elastic behavior of the modified binder has insignificantly changed compared to conventional asphalt binder. Apart from that, the performance on fatigue resistance after long-term aging is reduced since the elasticity after adding polyolefin has insignificantly changes. A further study is necessary to quantify how the molecular arrangement of the polyolefin changes during the aging process since the stiffness and elasticity of modified asphalt binder is changed after short-term aging (STA). This study helps to understand the reason behind the alteration and how it effects binder stiffness in details.

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Asphalt binder is a byproduct of the crude oil distillation process. The asphalt binder, which is one of the fundamental components of asphalt mixtures, substantially influences the asphalt pavement's performance. One of the most significant weaknesses of these pavements is their low resistance to fatigue and rutting, which is dependent on the number of loadings, ambient conditions, and interactions between these elements.

Over time, the asphalt binder performance declines as traffic loads and volumes rise, and it is unable to resist and endure the loads, thus damaging the roads. Consequently, modifying the asphalt binder and mixture is one of the options that can be considered (Fatemi et al., 2022). Another researcher also mentioned that the use of fiber reinforcing techniques to improve the asphalt is a promising research strategy. to overcome these problems (Wan et al., 2021). One of the examples of fibers is a polypropylene plastic which is a polyolefin polymer (Fethiza Ali et. al., 2022). There was a difference between base asphalt binder and polymer in terms of molecular weight and polarity. Thus, it causes a significant impact on compatibility when mixing both materials in either mechanical or chemical. For example, polyethylene which is one of the plastomer group has improve the stiffness to the binder and delay the deformation under traffic loading (Habib et al., 2010).

There are numerous strategies for preventing mixtures from early failure with fiber reinforcing being one of the most efficient methods for enhancing the performance of asphalt mixtures. This research focuses on the utilization of fiber as modifiers sources as one of the most effective strategies for achieving sustainable development in road construction. Reduce reliance on synthetic polymers while encouraging eco-friendly modifiers that offer comparable performance to synthetic polymers (Al-Hasan et. al, 2020). Polyolefin is a synthetic fiber mixture with a high tensile strength that is used to reinforce asphalt mixes in new construction and rehabilitation projects. The combination of aramid and polyolefin fibers is intended to complement the existing mix design. A researcher studied the effects of polyolefin-aramid fiber content on the performance properties of asphalt mixtures. The results show the asphalt mixture with fibers enhance the rutting resistance, mixture's resilience to fatigue and cracking, as well as the polyolefin component (Ziari et al., 2020).

Due to several conditions, asphalt binder characteristics change. Asphalt binder aging is one of the causes of a reduced pavement service life. Asphalt aging can be classified into two types: STA and long-term aging. Asphalt which was undergone a STA, experienced a deterioration during the mixing and paving processes. Apart from that, the long-term aging refers to the deterioration of asphalt throughout road service due to the several factors such as heat, water and light. Therefore, to have a clear understanding on the effect of aging, a study on binder or asphalt mixture can be done by using the rolling thin film oven test (RTFOT) and pressure aging vessel (PAV).

1.2 Problem Statement

The asphalt binders rheological and physical characteristics extensively affect loading responses in asphalt mixtures wherein the asphalt binder are acts as glue that bond together with the aggregates. The collected results regarding the use of polyolefin in the wet method indicate that a 6 % mixture is required for an optimal mechanical performance such as stiffness, penetration, and softening point of asphalt binder. However, the results had proven that the improvement of asphalt binder does not increase after a certain amount of fiber was reached. However, the compatibility between asphalt binder and polymer is a well-established concern (Daniel, 2020). Apart from that, the additional fibers into the asphalt binder through the wet mix process are able to improve the performance of asphalt binders in terms of physical and chemical characteristics. Several studies conducted by several researchers such as Garcia et al., 2012 (use of steel fiber), Hamedi et al., 2018 (use of polypropylene), and Kim et al., 2018 (use of polyester) have shown that the addition of fibers through the wet mix at appropriate concentration can improve the adhesion, mechanical and rheological performance of asphalt binder. Therefore, the study will be conducted on the usage of Super Fiber Mix (SFM) as the asphalt modifier would suspect being able to improve the characteristics of the asphalt binder. The SFM contains polyolefin and aramid fibers to reinforce asphalt mixtures.

Unfortunately, a very limited research and report on the effect of the addition of SFM available for modification using mix design used in Malaysia road industries. The effects of the polyolefin fiber which melts at approximately 120 °C are not well discussed. Therefore, it is important to understand the effect of polyolefin in the asphalt mixture incorporated SFM considering more than 3,000,000 m^2 of roads were paved with SFM. Therefore, a study towards the effects of adding the polyolefin on the binder properties by using wet method will be conducted. Several physical tests such as penetration, softening point, ductility, elastic recovery and rheological tests such as dynamic shear rheometer (DSR), Multiple Stress Creep Recovery (MSCR) and rotational viscosity (RV) is needed to be conducted to compare with the conventional binder as a reference binder. Thus, the performance of modified asphalt binder will be studied as one of the latest approaches that can improve the stiffness of asphalt pavement.

1.3 Objective

The overall goal of this research is to assess the effects of the SFM on the modified asphalt binder behavior. The objectives of this research are:

i. To determine the rheological properties of asphalt binder using modified binder.
ii. To evaluate the effect of short-term and long-term aging on properties of modified binder.
iii. To compare the rheological properties of the modified binder with the conventional binder.

1.4 Scope of Research

The laboratory assessment is focused on the SFM as the modifier in the asphalt binder. The conventional 60/70 penetration grade asphalt binder and the SFM are used in this research. The SFM is separated into two types of material which are polyolefin and aramid fibers. Both unmodified and modified binders have undergone an aging process to determine the physical and rheological properties change during the short and long-term aging of asphalt binders.

Both modified and unmodified binders at unaged conditions have been tested by physical properties test (penetration, ductility, softening point, flash point, elastic recovery, and torsional recovery) and rheological test (DSR, MSCR and RV). While aged condition for unmodified and modified asphalt binder has only been tested by rheological test. For each physical test, two samples were prepared and three samples for the rheological test.

1.5 Significance of the Research

This research extended the knowledge boundaries related to using the SFM in road construction. It was proven that the application of the SFM reduced the need for timely maintenance and rehabilitation of road networks. The performance over service life is improved due to the addition of the SFM. Significant improvement against rutting and a longer life span is reported. Adding polyolefin fiber at 0.05% by mass, the total mix had significantly improved thermal cracking occurring at low and rutting at high temperatures. Incorporating fiber in the mixture can prolong the pavement's lifespan due to improving rutting and fatigue.

By understanding the effects of the polyolefin in the asphalt binder, the reliance on the higher performance grade binder, which is expensive (PG 76), can be minimized. The cost of porous asphalt in Malaysia that uses PG 76 is more affordable to be applied in large areas such as PLUS Expressway and coincides with Sustainable Development Goals (SDG) 11. However, in-depth studies are required to ensure the homogeneity of the asphalt mixture due to the addition of polyolefin. Besides, the addition of polyolefin in asphalt binder can reduce carbon emissions compatible with SDG 13: Climate action.

1.6 Thesis Organization

This dissertation is separated into five chapters which are precise as follows:

Chapter One is an introduction to SFM used to reinforce asphalt mixes and problem statement, research objectives, the scope of research and the significance of the research.

Chapter Two is about the literature review based on the previous research on asphalt binders and the usage of the polymer as a modifier in asphalt binders. This chapter also reviews the effect of aging in asphalt binder and the effect of fibers on asphalt binder characteristics.

Chapter Three is described in detail the flows in conducting the test of the research study. The materials characterization, test procedure according to the standard method for asphalt binders, and the preparation of binder conditioning to obtain short-term and long-term aging.

Chapter Four discussed the results and data analysis that obtain from the laboratory testing. This chapter discusses the effect on the physical and rheological properties of asphalt binders by comparing conventional binders and modified asphalt binders. The binder condition effect after performing short-term and long-term aging is also presented in this chapter.

Chapter Five is about the findings of the research and the recommendation to be a consideration for future research. It will provide other researchers with a clearer understanding of how to conduct research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter reviews the previous study that have been done by researchers regarding the polymer used as a modifier in asphalt binder. In this chapter, the mechanism of polymer fiber, effect the on aging of modified binder, and modified asphalt binder characteristics have been elaborated in detail.

2.2 Introduction to Polymer Fiber

A study conducted by Chen et al (2022), it was found that the use of fiber reinforcing to modify the asphalt is a promising strategy to overcome these problems. It had been centuries, the fibers was employed to strengthen brittle materials by increasing the toughness, tensile strength, and durability (Morea and Zerbino, 2018). The synthetic polymer had been used after World War 2. A patent was issued for a bituminous compound containing base asphalt binder and polyisobutylene in 1940. In the 1950s, neoprene (polychloroprene) latex was progressively employed in North America for asphalt binder modification (Zhu et. al., 2014). Various types of polymers have their own characteristics in providing asphalt binders with the necessary qualities to improve its properties. The characteristics of polymers are elastomers (e.g. styrene-butadiene diblock (SB), styrene butadiene styrene triblock (SBS), and styrenebutadiene rubber (SBR)) and plastomers (e.g. polyethylene (PE), polypropylene (PP) and polystyrenes (PS)) (Eskandarsefat et al., 2022). Elastomer provided an excellent elastic property that is suitable for pavement in both cold and warm climates. Moreover, plastomers with the ability to improve the mechanical properties of asphalt pavement, making them ideal for use in countries with moderate to high temperatures and heavy traffic.

In order to enhance the performance of asphalt pavement at extreme temperature variations, the incorporation of polymer fiber is required to improve the lifespan and to reduce the long-term cost of road construction and maintenance (Daniel, 2020). Polymer modified binders generally increase the viscosity and offer higher resistance to permanent deformation than conventional binders and exhibit enhanced adhesion to aggregate particles (Eskandarsefat et al., 2022)..

2.3 Polymer Fiber Molecular Structure and Composition

Aromatic polyamide (aramid) is a set of synthetic polymers (substances that made up of several molecules that form a long molecular chains), in which repeating units with large phenyl rings are linked by amide groups. Amide groups (CO-NH) form strong, solvent and heat-resistant bonds (William, 2009). Furthermore, Daniel (2020) states that Poly Para-phenylene terephtalamide (PPD-T) known as aramid was the end product of condensation process between 1,4-Para-Phenylenediane (PPD), and Terephthaloyl Dichloride (TDC). The molecular structure of aramid fiber can be referred from Figure 2.1. Aramid has good heat resistance and low flammability, so it only degrades instead of melting after being heated (Daniel, 2020). In addition, their extremely low electrical conductivity makes them perfect electrical insulators (Todd, 2018). The physical qualities of aramid fiber are influenced by its molecular structure due to the aromatic ring structure, which provides great thermal stability, stiffness and strength. However, aramid fiber is sensitive to ultraviolet light, acids, and salts.

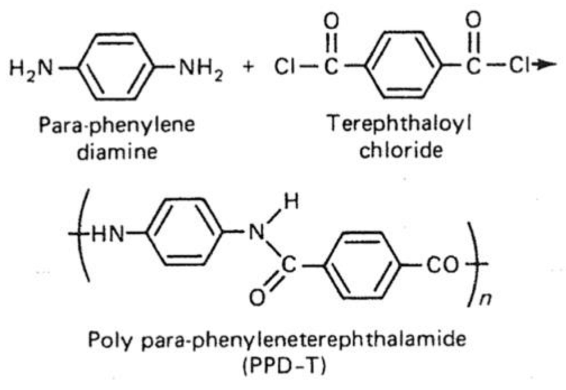

Figure 2.1 Molecular structure of aramid fiber (Daniel, 2020).

Another type of synthetic fiber is polyolefin. It is a class of synthetic thermoplastic polymers that includes two subgroups, such as polyethylene (PE) and polypropylene (PP). Materials with two or more phases (chemical and physical) are known as polyolefin composites (POCs) (Al-Thani et al., 2016). Both polypropylene and polyethylene are derived from the same monomer. This is due to their molecular structures that are fundamentally an asymmetric chain of α-olefins with general formula $CH_2{=}CH_x$, where *x* is an alkyl group. Therefore, polypropylene will evolve in a similar manner as polyethylene (Daniel, 2020). However, the variations in molecular weight and polarity of the base asphalt binder and polymer had a major impact on their compatibility. Thus, asphalt binder mixed with polyolefin will increase its viscosity due to the structural changes even there was a small increment in volume of modified asphalt binder (Habib et al., 2010).

The Essential Chemical Industry, 2016 states the addition polymerization of propene yields poly(propene), often known as polypropylene. Polypropylene is a form of polyolefin which is significantly tougher than polyethylene. It is a commodity plastic with low density and strong heat resistance. By referring to Omnexus (2022), Polypropylene (PP) is a thermoplastic that is tough, stiff, and crystalline. It is derived from propene (or propylene) monomer where $(C_3H_6)n$ is the chemical formula for the linear hydrocarbon resin. Therefore, the basic chain structure is based on the position of methyl group (e.g., isotactic and syndiotactic). Figure 2.2 shows the isotactic polypropylene. The molecules of isotactic polypropylene form helices due to their "one handed" shape. This consistent structure causes the molecules to crystallize into a hard, moderately solid substance that melts at 440 K in its purest form. Polypropylene was classed as a thermoplastic material, due to its response to heat. This is because polypropylene material will change its phase from solid to liquid when it reached its melting point. According to the Creative Mechanisms Staff (2016), the ability of thermoplastics is it does not degrade significantly even after being induced to several cycle of heat (to its melting point).

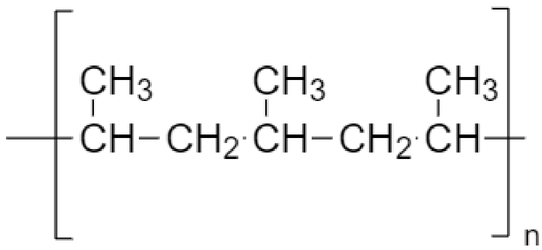

Figure 2.2 The isotactic polypropylene molecular structure (Hagen et. al., 2002).

Apart from polypropylene, polyethylene terephthalate (PET) also able to remold and reform repeatedly due to the ability to reverse the structure heating. PET comes from a group of polyesters that is solid, strong, semi-crystalline, and colorless in its natural condition depending on the preparation technique (Ashoor et. al., 2019). The formation of PET is based on polymerization of ethylene glycol and terephthalic acid. Large aromatic rings found in PET (Figure 2.3) provide the material stiffness and strength, especially when the polymer chains are arranged in an organized manner (Erik, 2020; Ashoor et. al., 2019). Even with good performance in term of strength and rigidity, but it is less flexible, and has a lesser chemical resistance according to Omnexus (2022).

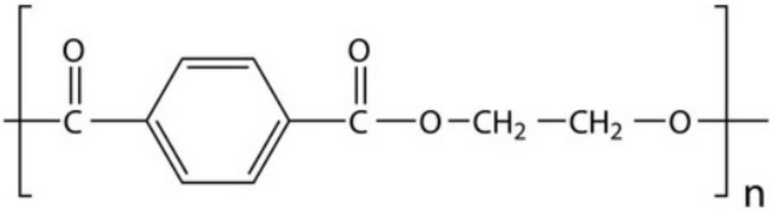

Figure 2.3 Molecular structure of PET (Omnexus, 2022).

Besides that, polystyrene (PS) is a synthetic aromatic hydrocarbon polymer having the chemical formula $(C_8H_8)n$. PS is a synthetic aromatic hydrocarbon polymer that can be in either solid or foamed as its made up from the styrene monomer as shown in Figure 2.4. Polystyrene is a thermoplastic polymer that is solid (glassy) at room temperature but flows above its glass transition temperature of approximately 100°C (Assignment Point, 2022). The presence of pendant phenyl (C_6H_5) groups is essential to polystyrene's characteristics. In addition, the phenyl rings inhibit the rotation of the chains around the carbon-carbon bonds, so imparting the polymer with its renowned stiffness (Amy, 2018). According to Chandra et al. (2016), this chemical structure provides polystyrene with advantageous characteristics, such as low weight and high strength.

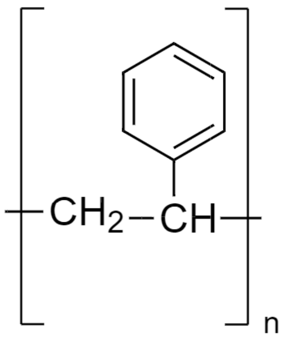

Figure 2.4 Molecular structure of polystyrene (PS) (Qin et al., 2018).

2.4 Effect of Aging on Asphalt Binder

Under a certain circumstance, the asphalt binder will undergo aging process. The aging mechanism start with oxidation, evaporation, and end with physical hardening. By limiting oxygen's access to the asphalt binder, void content determines the rate of aging (Lu et al., 2008). The more reactive elements of asphalt react to the oxygen, the larger the causes of asphalt hardness, viscoelastic loss, and cracking. The consequences are diverse with different types of asphalt (Hernando et al., 2015). The effect of aging cause the increase of large molecular content and decrease in small molecular content, resulting in a rise of asphalt binders' molecular weight. Aging also reduces aromatics while simultaneously increasing the resins and asphaltenes contents. In addition, it was discovered that artificial aging increases the amount of carbonyl compounds and sulfoxides in conventional asphalt binder materials (Hamzah et. al., 2015).

The investigation of fundamental characteristics with penetration value at 25°C and softening point temperature has showed a variation after RTFOT with varied STA temperatures. This distinction increase the softening point following PAV and reduce the penetration value (Hofko et al., 2017). Kumbargeri and Biligiri (2016) study the aging behavior of two typical base asphalt binders which were used in India's road construction. Observations indicate a major change of asphalt binder's behavior as it ages. This was demonstrated by the variation in penetration, softening point, and viscosity values. Another study conducted by Akbar (2019) to investigate the physical properties of waste polystyrene modified binder and unmodified asphalt binder (60/70 grade) after thermo-oxidative aging (TFOT). It was found that polymer modification leads to a significant decrease in temperature susceptibility, especially at higher polymer concentrations. In Superpave, $G^*/\sin(\delta)$ was widely used to determine the asphalt binder's grade according to their resistance towards rutting at temperature above 46°C (Al-Khateeb et. al., 2019). Therefore, Fatemi et al. assessed on the amorphous poly alpha olefin (APAO) modified asphalt binder through its rheological properties. The result showed that the rutting resistance parameter increased after the RTFO aging. The effect showed may possibly a result of asphalt binder evaporate its volatile elements and formation of asphaltene through the conversion of aromatics and resins. Thus, APAO-modified asphalt binders improved the $G^*/\sin(\delta)$ parameter for all types of pre/post-aged RTFOT asphalt binders, indicating that post-aged RTFOT asphalt binders stiffened and, thus, increased the rutting resistance of respective mixtures (Fatemi et al., 2022). Moreover, another study to evaluate the effect of the high-temperature stiffness ($G^*/\sin(\delta)$) of the binders based on the 35/50 and 50/70 paving-grade asphalt binder was conducted. The result showed both of asphalt binder stiffness after RTFOT aging were significantly higher than unaged binder by measuring $G^*/\sin(\delta)$ at 70°C (Maciejewski et. al., 2021).

A study conducted on DSR of unaged, short-term, and long-term aging of asphalt binder samples by using different temperatures (58, 64, and 70°C). All the results showed that the test temperature at 64°C meets the minimum requirement based on the Superpave criteria. A performance grade (PG) for 60/70 asphalt binder was determined based on the results of this test, which is PG 64 (Azzam and Al-Ghazawi, 2015).

2.5 Effects of Polymer Fiber on Asphalt Binder Characteristics

Asphalt binder modified with polyolefin was found to increase the softening point and reduces penetration grade (Danial, 2020). So, it was proved to improve the deformation resistance. The researcher used polyethylene and grafted polyethylene-based polymers as a modifier. The results show the penetration decreases at 25°C, allowing for enhancement in shear resistance at temperatures of medium and high. Softening points tend to rise with the addition of polymers, indicating improved deformation resistance (Vargas et al., 2013). Based on the review by Abdy et al. (2022) on polyolefin, plastics modifier, they found that the penetration (increasing stiffness) decreases, and softening point of the binder increase as the proportion of polymer increases. They also observed a substantial increase in viscosity with increasing plastic dosage. Another research had investigated the effect of Waste Polystyrene on performance of asphalt binder by using a various percentage. According to the finding, the viscosity increased significantly at temperatures of 60°C and 135°C (42% and 137%, respectively). Meanwhile, the softening temperature increased by 18°C compared to the base asphalt binders, and the penetration fell by 29.5%. However, it was discovered that penetration appears to be less influenced by polymer loading rates, despite a small decrease in the penetration values of the changed samples throughout the range of 2–6 wt% (Akbar, 2019). Nevertheless, according to Majer and Budziński (2021a), the additional of aramid-polyolefin fibers does not have any changes for penetration test and softening point test. The result shown only the value decrement was too small from the conventional binder. Thus, the physical changes of the asphalt binder can be negligible.

Gupta et al. (2021) studied the effect of aramid fiber in porous asphalt mixture. The result of multiple stress creep recovery (MSCR) test proved that strain recovery of asphalt mixture incorporated aramid fibers was improved. Vargas et al. (2013) was also discovered that the addition of polyolefin could improve the complex shear modulus (G*) of asphalt binder. Results shows that modification of binder using recycle Low Density Polyethylene and recycle High Density Polyethylene gives a higher binder complex shear modulus (G*) and a lower loss tangent (tan δ) which improved rut resistance behavior (Alghrafy et. al., 2021). Cardone et al. (2014) also reported that the addition of a polymer network to an asphalt binder modified with SBS, and polyolefin causes the material to become stiffer, have a smaller phase angle, and be less sensitive to temperature changes. Meanwhile, according to Fatemi et al. (2022), the addition of APAO to conventional asphalt binder increased the high temperature performance of conventional asphalt binder by two grades (PG 64 to PG 76). APAO decreased the Jnr value of virgin asphalt binder, indicating that asphalt binder modified with APAO has a greater resistance to rutting. The rutting performance became better as the amount of APAO increased. Moreno et al. (2015) investigates the impact of polymer-modified binders on asphalt mixture’s mechanical performance over the long term by using the different percentage of SBS polymer. At high temperatures, polymers make the binder more consistent by decreasing its phase angle and making it less thick. At low temperatures, polymers make the binder more flexible by increasing its phase angle and making it less stiff. Also, adding polymers makes the binder's response to temperature more stable from a rheological point of view. Thus, as polymer content increases, the differences in phase angle between high and low temperatures decrease.

The additional lower molecular weight (Mw) LDPE for 3–5 wt% will boost chain mobility, which will prolong the binder's fatigue life (Roja et al., 2021). Polyolefin plastic failed to increase asphalt binder's elastic recovery, causing fatigue cracking at low temperatures (Zhang et al., 2021). Due to the long chain structure of PE, it tends to crystallize and pack securely, which preventing the contact between the modified asphalt binder and polymer that causes instability. In addition, up to a certain amount, the ductility of the polyolefin modified binders can be maintained within a given minimum range (100 cm) (Abdy et al., 2022).

2.6 Summary

Based on the literature review, it can be concluded that using the polymer as a modifier in the asphalt binder has its respective advantages. Polymer-modified asphalt binders have been widely used to enhance the properties of virgin binders. The improved polymer binder increases flexural fatigue (crack resistance) and rut and shoves resistance due to increasing the amount of polymer until optimum. The effectiveness of polymer-modified asphalt binders has been established both in the field and in the laboratory. Efforts are ongoing to establish a correlation between laboratory results and field performance.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The test conducted a series of testing on the asphalt binder to evaluate its physical and rheological properties of the asphalt binder. The materials need to perform binder conditioning before being tested to get the performance evaluation of the asphalt binder. This test carried out the purpose of the laboratory work is to promote polyolefin as the material alternative to enhance the rutting and fatigue performance with asphalt binder. This chapter indicates detailed information about materials and experimental procedures according to the design standard to achieve the research objective.

3.2 Materials

3.2.1 Asphalt Binder

Asphalt binder is produced via aeration on vacuum bottom (the raw material used to make asphalt binder is left in vacuum distillation columns in oil refineries). The conventional penetration grade of asphalt binder used in this research is 60/70 grade. Asphalt binder 60/70 grade is ideal for road construction and superior asphalt pavements. The physical properties of asphalt binder used in this research work are as summarized in Table 3.1.

Table 3.1 Physical properties of asphalt binder 60/70 grade

Properties	Test method	Value	Unit
Specific gravity at 25 ˚C	ASTM D 70	1.039	kg/cm3

Penetration at 25 ˚C	ASTM D 5	63	dmm
Softening point	ASTM D 36	48	˚C
Ductility at 25 ˚C	ASTM D 113	>100	cm
Flash point	ASTM D 92	322.5	˚C
Elastic recovery at 25 ˚C	ASTM D6084	2.5	%
Torsional recovery at 25 ˚C	Austroads AG: PT/T122	1.95	%

3.2.2 Super Fiber Mix (SFM)

SFM needs to separate manually into two types of materials: polyolefin and aramid fiber. Then, the fiber is weighed based on the percentage given by the local vendor, which is 0.05% of the total weight of the asphalt mix. SFM is a combination of two synthetic fibers which is polyolefin and aramid fibers. This fiber blend with high tensile strength is designed to reinforce asphalt mixtures in new construction and rehabilitation projects. Plate 3.1 shows the polyolefin fiber that has been separated from aramid fiber. In Malaysia, AHN VERTEX Sdn. Bhd. is the only company that distributes the SFM.

The combination of aramid and polyolefin fibers is intended to complement the existing mix design. Details of the physical properties of SFM fiber can be shown in Table 3.2. Previous research indicated the use of fiber in asphalt mixture to enhance the resistance against fatigue and cracking. However, there are limited studies on the physical and rheological properties of asphalt binder and the effect of asphalt binder after short-term and long-term aging process when adding polyolefin fiber as a modifier by using a wet process that requires further research.

Polyolefin

Plate 3.1 Picture of polyolefin fiber

Table 3.2 Physical properties of SFM fiber (Majer and Budziński, 2021)

Fiber	**Polyolefin**
Form	Serrated
Color	Yellow
Density (g/cm^3)	0.91
Length (mm)	19
Tensile strength (MPa)	N/A
Operating temperature	N/A
Acid/Alkali resistance	Inert

Based on the information that provided from AHN Vertex, by using Marshall mix design approach, it was found the optimum binder content (OBC) for the conventional asphalt mix was 5.2%. The total mass in the asphalt binder for 10 kg can be determined and the polyolefin is added to the asphalt binder in as many as two bags (approximately 4.35 g) provided by AHN VERTEX Sdn. Bhd. The amount of polyolefin fiber can be negligible as the percentage of the fiber in the mixture was only 0.05% of the total mass of the asphalt binder.

3.3 Research Methodology Flow Chart

The experimental work that was conducted as shown in Figure 3.1. The research work had been started with classification the SFM fiber into two material which are polyolefin and aramid. In this research, only polyolefin had been used and mixed together with asphalt binder while aramid fiber is not used due to high melting point (not dissolved in asphalt binder).

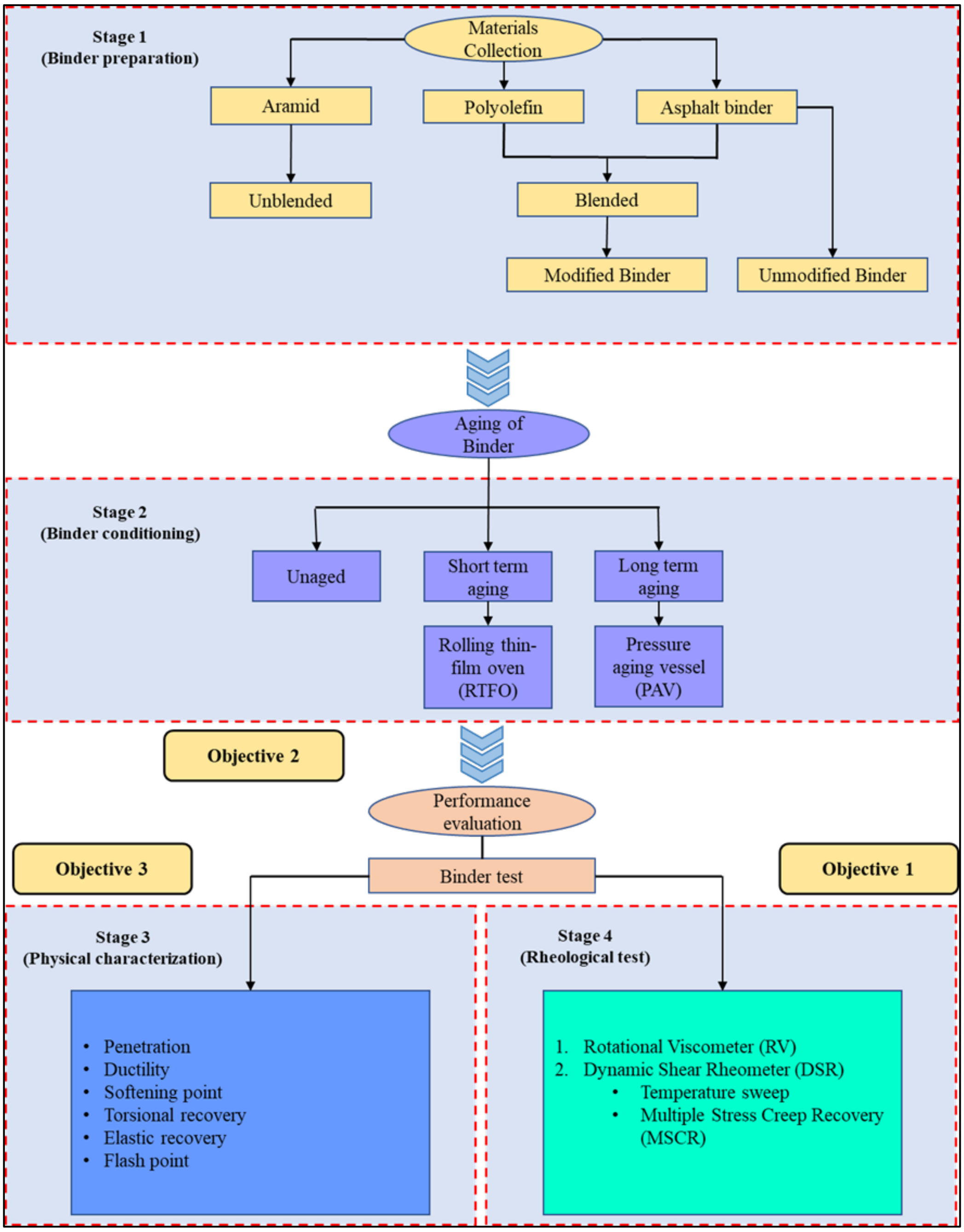

Figure 3.1 Structure of the Experimental Plan

3.4 Laboratory Assessment on asphalt binder

Generally, the following tests are used to evaluate the various characteristics of bituminous materials. Asphalt binder is subjected to a variety of tests to determine its consistency, gradation, viscosity, temperature susceptibility, and safety.

3.4.1 Specific Gravity of Bituminous Material

Density of Semi-Solid Bituminous materials method used to determine the specific gravity and density of asphalt binder by using a pycnometer method. The test was conducted based on standard method in ASTM D70. The sample was placed in calibrated pycnometer that shows in Plate 3.2. The pycnometer containing asphalt binder is weighed, the remaining volume was filled with water. The pycnometer is tested at 25 ˚C and the density of sample calculate from mass of sample and water displaced by sample. The density of the asphalt binder can be calculated using Equation (3.1). The specific gravity of asphalt binder can be determined using Equation (3.2).

$$density, g/cm^3 = \frac{C - A}{(B - A) - (D - C)} \tag{3.1}$$

where;

A = mass of pycnometer with stopper,

B = mass of pycnometer filled with water,

C = mass of pycnometer partially with sample, and

D = mass of pycnometer filled with water and sample

$$Specific\ gravity = \frac{density}{W_T} \tag{3.2}$$

where;

W_T = density of water at 25 ˚C (0.997 g/cm^3)

Plate 3.2 Calibrated pycnometer

3.4.2 Penetration of Asphalt Binder

Penetration Grade of asphalt binder is a common test that is typically used as a paving grade. The penetration test is performed to determine the asphalt binder's consistency and hardness. This testing was performed in accordance with ASTM D 5's specifications. The asphalt binder sample penetrated at temperature of 25°C by a needle carrying 100 g load for 5 seconds.

3.4.3 Ductility of Asphalt Binder

The ductility test is used to determine the ductility of the asphaltic binder used in road pavements. For flexible pavement design, it is required that the binders produce a thin, ductile film around the aggregates in order to increase the aggregates' physical interlocking. This test was conducted in accordance with the procedure provided in ASTM D 113. The ductility test is measured in centimeter (cm) and the sample is immersed in water continually while the two clips are pushed apart at a consistent rate until separated at speed 5cm/min. Plate 3.3 shows the ductility mold used for this laboratory test.

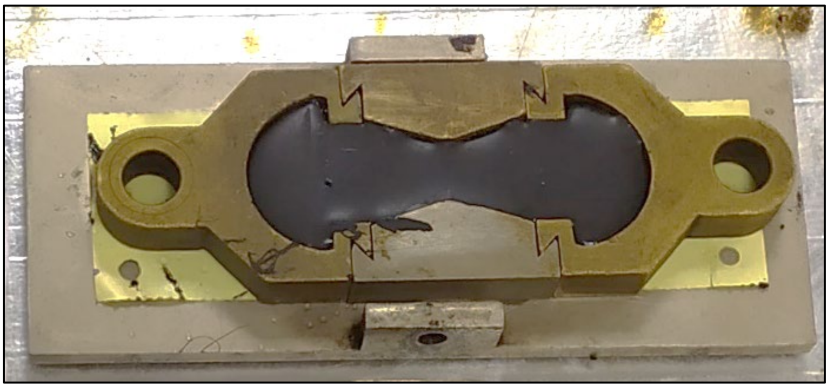

Plate 3.3 Ductility mold

3.4.4 Softening Point of Asphalt Binder

Asphalt binder is a viscoelastic substance without a clearly specified melting point. Asphalt binder tends to become less viscous and softer as temperature rises. Due to this, the softening point of both the changed and unmodified asphalt binders was tested by method of Ring and Ball. The softening point test was conducted in accordance with the procedure provided in ASTM D36. A asphalt binder sample is tested until it no longer supports the weight of a 3.5g steel ball and the softening points of the asphalt binders were taken as the temperatures. The samples are heated at constant rate of 5°C per minute in water bath for 15 minutes then the sample heated at temperature of the water rises at 5 ± 0.5°C per minutes for the first 3 minutes until the ball touch the base plate.

3.4.5 Torsional Recovery of Asphalt Binder

A torsional recovery test measures the elasticity rendered by a polymer towards an asphalt binder. This test is conducted to characterize the effect of different type of asphalt binder condition. A basic bolt and cup arrangement was used to conduct the torsional recovery test. The embedded aluminium bolt in the cup of the asphalt binder was rotated 180°C and the extent to which the initial rotation was recovered was determined. After removing the band, the asphalt binder sample was allowed to recover for 30 seconds before the reading was recorded. The torsional recovery can be calculated using Equation (3.3).

$$Torsional\ Recovery, \% = \frac{A}{180} x100 \tag{3.3}$$

where;

A = the recovered angle, in degrees.

3.4.6 Elastic Recovery of Asphalt Binder

The elastic recovery of asphalt binder is calculated as a percentage of the distance between the ends of the half-threads 30 minutes after division in relation to a 100 mm elongation length. The mold used in this test is difference as ductility test as shown in Plate 3.4. The specimen is stretched to a predetermined elongation at 25°C and at a constant rate of 50 mm/min. During this test, the asphalt binder specimen yarn so obtained is cut in the middle to obtain two half-threads whose shrinkage will be measured. Elastic recovery can be obtained by using Equation (3.4).