Study the Performance of Modified Asphalt Mixture Using Styrene Butadiene Styrene

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Abstract. Hot mix asphalt pavement is a conventional mix that has been used to serve the transportation world. Nevertheless, at certain period of time, many problems had been arise due to its poor performance in term of temperature sensitivity and increased in traffic loading. In response to that, a lot of research has been conducted to determine the best alternative that can contributes on improving the performance of asphalt pavement. One of the methods is by using polymer modified bitumen in asphalt mixture. Among the various types of polymers, Styrene Butadiene Styrene (SBS) polymer is the ones which widely used due to its effectiveness on improving the mechanical properties of asphalt mixture such as low temperature cracking, fatigue cracking and rutting. This study presents an evaluation of performance of modified asphalt mixture using SBS polymer. Marshall test was conducted for determining of Optimum Bitumen Content (OBC) of control specimen. The OBC value was then used in the preparation of control and SBS modified sample. Subsequently, several laboratory test include Indirect Tensile test, Resilient Modulus test and Dynamic Creep test were carried out to determine the performance of both samples. Results obtained from the test were then compared between control specimen and SBS modified asphalt sample. The results indicate that there was significant improvement of asphalt performance due to SBS additive. The modified sample was proven to be less susceptible to cracking and rutting, which resulted to be better resistance against permanent deformation than the conventional ones.

Introduction

Hot mix asphalt can be explained as the combination of aggregate uniformly mixed and coated with the asphalt cement. The term of “hot mix” originally comes from the process of heating of the proper mixing of the aggregate and cement with the specified temperature. Asphalt cement has an important role to bind the HMA pavement together. It consists of viscoelastic material, which demonstrates both viscous (fluid-like) and elastic (solid-like) characteristics. Both characteristics are widely influence by the temperature.

As the world nowadays has been urbanized for development purpose, it generates more heat. Consequently, the HMA pavement also has its own flaws since it is temperature dependent. For instances, the asphalt cement behaves like solid at low temperature, while becoming soften at high temperature. Extreme temperature for both conditions can develop a negative effect on the HMA pavement’s performance. At low temperature, the road becomes brittle and develops fatigue cracks. In comparison, higher temperature lead to deformation related failure such rutting or permanent deformation and slippage.

Pavement with polymer modification exhibits greater resistance to rutting and thermal cracking, and decreased fatigue damage, stripping and temperature susceptibility [1]. Among the various types of polymers, SBS polymer is widely used to improve the properties of asphalt mixture. Therefore, this study was conducted to evaluate the performance of modified asphalt mixture using styrene butadiene styrene (SBS). The objective of this study was to obtain the optimum bitumen content and followed with the performance evaluation between SBS modified mix and conventional mix.

The scope of this study focused on evaluation of performance of modified mix asphalt with polymer type of SBS only. The asphalt mix used was 80/100 PEN for AC14 mixture. In this study, the 5% of SBS was added to bitumen (by bitumen content weight). The preparation of the asphalt mixtures was accordance to standard testing for Marshall Design Mix. All the samples for the study were prepared using UTM laboratory apparatus and machinery.

Previous Studies

The conventional mix design in road construction is sufficient enough for normal traffic condition. However, increase in number of vehicle and high axial loads demand for stronger binder which is resulted in modification of asphalt. Modification of asphalt mixture in road pavement has been implemented over the world to improve the performance of the conventional pavement. Modified asphalt mixture can bring real benefits to road construction in terms of better and longer lasting roads, and cost savings in road maintenance.

Modification of asphalt binders can serve several purposes. It can enhance the overall performance of a binder by widening the range between the binder's high- and low temperature grades, or it can target a specific improvement in a binder's performance in response to a particular severe-service condition, such as a pavement carrying a very high traffic volume or a high percentage of slow-moving, heavy vehicles [2]. Polymer is one of the modifiers that commonly used in last few decades to improve the conventional ones. Polacco *et al.* [3] stated that Polymer-modified asphalt (PMA) derive their technological and conceptual origin from the need for enhancing the performance and durability of asphaltic materials as well as their adhesion to mineral aggregates. For a polymer to be effective in road application, it should properly blend with bitumen to produce a homogenous mix to improve its resistance to rutting, stripping, cracking, fatigue, ageing, etc. [4].

Polymer can be categorized in elastomer and plastomer. Thermoplastic elastomers are obviously able to confer good elastic properties on the modified binder, which are more resilient and flexible, hence can easily recover from deformation, while plastomers and reactive polymers are added to improve rigidity and reduce deformations under load [5]. The examples of elastomers used in bitumen modification include natural rubber, styrene butadiene strene (SBS), polybutadiene, polyisoprene, isobutene isoprene copolymer, polychloropren and styrene butadiene rubber [6]. In contrast, plastomers are more rigid, tough, but may be brittle. Plastomers type of polymer has higher deformation resistance, higher stability and stiffness moduli. Plastomers include ethylene vinyl acetate, polyethylene (unstabilized and stabilized) and various compounds based on polypropylene [7].

SBS block copolymer is classified as elastomer that increases the elasticity of bitumen [1, 8]. The structure of a SBS copolymer therefore consists of SBS tri-block chains, having a two-phase morphology of spherical polystyrene block domains within a matrix of polybutadiene [6]. Public Roads Department [9] clarified that the polymer does not chemically combine or change the chemical nature of the bitumen. When SBS is blended with bitumen, the elastomeric phase of the SBS copolymer absorbs the maltenes (oil fractions) from the bitumen and swells up to nine times its initial volume. At suitable SBS concentrations (commonly 5–7% by mass), a continuous polymer network (phase) is formed throughout the PMB, significantly modifying the bitumen properties [6, 8]. However, Yildirim [1] specified that if polymer phase was not homogeneously distributed, it might have been caused the poor performance of the pavement.

SBS modified asphalt samples were prepared by melt blending method. The neat asphalts were first heated in the cylindrical vessel to 175 °C and the SBS copolymers were added to asphalt and sheared for 30 min on a high shear mixer at 4000 rpm. Afterwards, asphalt–SBS blends were stirred for 3 hours to ensure homogeneous mixtures [10]. Polymers are usually provided in the form of pellets or powder which can be subsequently diluted to the required polymer content by blending with base bitumen by using low to high shear mixer. Blending pellets of with base bitumen results in a special polymer concentration suitable for different applications [8].

The performance of asphalt pavement is mainly dependent on the mechanical and viscoelastic behaviour of asphalt which is impacted pronouncedly by the polymer properties [10]. The modified bitumen properties are significantly resulted on the asphalt performance of the pavement. The effect of SBS in terms of performance can be determined with several test includes Indirect Tensile test, Resilient Modulus test and Dynamic Creep test. Generally, the higher asphalt content result in higher plastic flow susceptibility. This may lead to the high permanent deformation due to too much asphalt content in the mix. From study, Tayfur *et al.*, [11] and Sengoz and Isyikaar [8] stated that the optimum asphalt content of SBS mixture was much higher than conventional mixture. In contrast, the modified mixture reveals to be more resistance towards permanent deformation.

Therefore, it can be concluded that, the polymer additives contribute to the adhesion ability of the aggregates of HMA. Thus, the better adhesion on aggregate reduce stripping problem in road surface. Several researches have been conducted relating the tensile strength of asphalt mixtures to the performance of asphalt pavement. Tayfur *et al.* [11] stated that SBS modifier resulted in higher tensile strength, which corresponds to a stronger low temperature cracking resistance. This also can further imply that modified mixtures appear to be capable of withstanding larger tensile strains prior to cracking.

Methodology

The experiment conducted is to determine the bitumen content (OBC) and evaluating the performance of modified asphalt compared to the conventional asphalt. All the laboratory testing were based on the standard specification on JKR/SPJ/2008 and ASTM. All the testing conducted using the facilities available in the highway and transportation laboratory.

The raw materials needed in this study consist of bitumen, aggregates and mineral filler. The aggregates were occupied from Malaysian Rock Product (MRP) quarry, located at Ulu Choh, Pulai, Johor. The hydrated lime was used as filler due to its availability in laboratory. The filler was treated as an anti-stripping agent. Sieve Analysis test was conducted to determine the grading of aggregate sizes for AC14 mixture in order to ensure the aggregate were well blended within the gradation limit as specified in JKR/SPJ/2008 [9]. As for modifier, Styrene Butadiene Styrene (SBS) was used as an additive and added to the asphalt in 5% from the bitumen weight.

Marshall Mixture Design Marshall Method [12] was used for determining optimal bitumen content for conventional and modified asphalt mixtures. Three identical samples were produced for all alternatives. Bitumen range region was 4.0%, 4.5%, 5.0%, 5.5% and 6.0% according to the bitumen demand for AC14 mixture. The bitumen used was 80/100 PEN. The test was conducted to determine the relationship between the bitumen content with density, stability, flow, stiffness, voids in the total mix (VTM) and voids filled with bitumen (VFB). From the analysis, the average value of bitumen content was checked according to JKR/SPJ/2008 [9] specification.

After determining the optimum bitumen content, the mixing of aggregate and bitumen was then carried out for preparation of control sample and SBS modified sample. The mixing temperature was 160oC and the compaction temperature was 125^{o}C to 130^{o}C. The procedure of preparation of specimens at OBC was repeated using Marshall Test [12]. 75 blows per side of specimen were applied with the compaction hammer by using free fall of 457mm. Three samples were prepared for each performance test for all alternatives mix.

Performance Test Three different types of performance test have been conducted in order to assess the performance of modified samples with SBS. These tests include Indirect Tensile Strength Test, Resilient Modulus test and Dynamic Creep test. The following sections discuss the tests in details.

Indirect Tensile Strength Test. The indirect tensile strength test (IDT) was used to determine the tensile properties of the asphalt concrete which can be further related to the cracking properties of the pavement. The standard procedure of Indirect Tensile test was accordance to ASTM D 6931 [13]. This test is summarized in applying compressive loads along a diametrical plane through two opposite loading strips. This type of loading produces a relatively uniform tensile stress which acts perpendicular to the applied load plane. The peak load at failure was recorded and used to calculate the tensile strength of the specimen. The test was conducted at 25°C for both conventional mixture and modified ones. The tensile strength of the specimen was determined by the following equation:

$$\mathrm{ITS} = \frac{2P_{max}}{\pi d t}$$

Where ITS is the indirect tensile strength (kPa); P_{max} is the maximum load (N); d is the diameter of specimen (mm); t is the height of specimen before test (mm).

Resilient Modulus Test. Resilient Modulus test measures time dependent deformation under constant compressive stress to evaluate the ability of compacted specimen to recover from repeated load cycles without reaching the failure limit. The test was conducted in accordance to ASTM D 4123 [14] under the indirect tensile mode using Universal Testing Machine (UTM) at a controlled temperature of 25°C and 40°C. Resilient modulus was used to as an index for evaluating stripping, fatigue and low temperature cracking of asphalt mixtures. The peak load of 1000 N was applied vertically in the diametrical plane of a cylindrical specimen and the horizontal deformation was measured. For this test, the specimens were tested in two orientations, 0° and 90°. As Poisson's ratio was assumed to be 0.35, thereby the resilient modulus was calculated.

Dynamic Creep Test. The dynamic creep test is also known as repeated load axial test was conducted using Universal Testing Machine (UTM) that applies a repeated pulsed uniaxial stress on specimen. The test was conducted to determine the resistance of the specimen to permanent deformation. The test was conducted according to BS EN 12697-25 [15]. This test applied 300 kPa cyclic loading stress to the specimen with 3600 termination cycles count and measures the deformation in the same direction using Linear Variable Differential Transducers (LVDT). In this study, this test was conducted at the temperature of 40°C for both mixture types.

Data Analysis

Sieve Analysis All aggregates were sieved to separate the aggregates according to the sieve sizes as stated according to specification. The median of the upper and lower limit of AC14 was chosen as the gradation to attain a gradation which is compliance with the specification provided by JKR/SPJ/2008 [9]. Figure 2 shows the gradation limit for AC14 mixture.

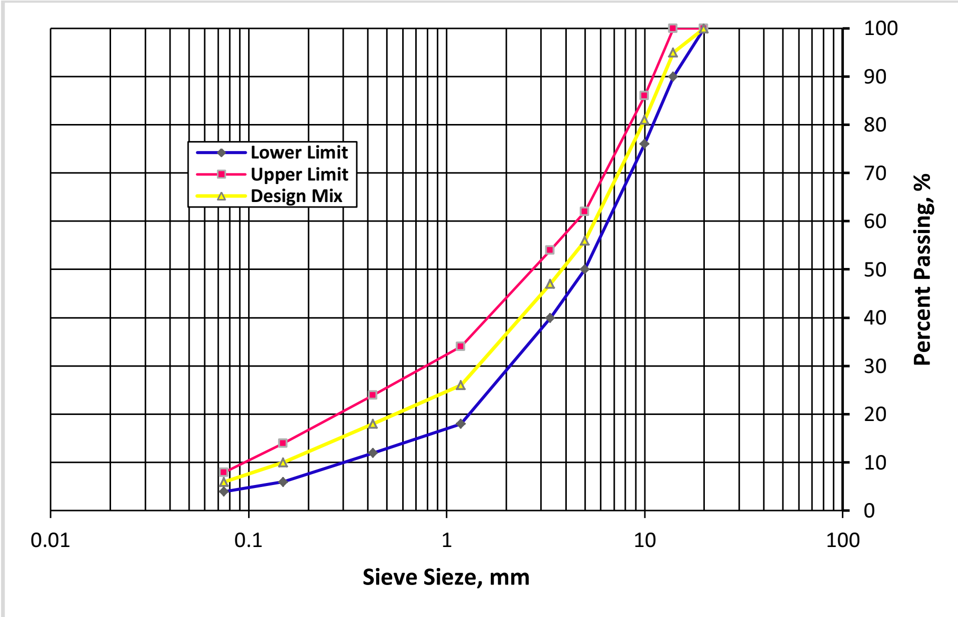

Figure 2: Plotted aggregate gradation limit for AC14

Optimum Bitumen Content The Optimum Bitumen Content (OBC) was determined before preparing samples for performance tests using Marshall mix design. The OBC for AC14 was determined by using trial bitumen content of 4.0%, 4.5%, 5.0%, 5.5% and 6.0% with three specimens produced for each. Therefore, a total of 15 specimens were prepared for the OBC determination. Data obtained from the test were analyzed and graph of density, stability, Void Total Mix (VTM) and Void Filled with Bitumen (VFB) against bitumen content were plotted.

From the calculation done, the value for OBC was 5.2%. Table 1 presents the results for the verification sample for control sample. Based on the result, the OBC of 5.2% had satisfied the Marshall properties from JKR/SPJ/2008 [9]. Thus, the OBC of 5.2% will further be used in the sample preparation of control sample and SBS modified sample.

Table 1: Verification sample result for control sample

Marshall Properties	JKR/SPJ/2008	Average
Stability	> 8000 N	18196
Flow	2.0 – 4.0 mm	2.73
Stiffness	> 2000 N/mm	6665.3
VTM	3.0 – 5.0 %	3.9
VFB	70 – 80 %	74.7

Indirect Tensile Strength Figure 3 shows the comparison of IDT strength for different types of mixture. There were total of three samples prepared for both type of mixtures in order to obtained particular data and result for this test. The results show that the IDT strength for modify asphalt mixture is 24% higher than control specimen (80/100 PEN). This proves that the addition of 5%

SBS in the asphalt mixture has higher values of tensile strength at failure under static loading. Related to that, this result also proves that modified mixture has a capability to withstand larger tensile strains prior to cracking.

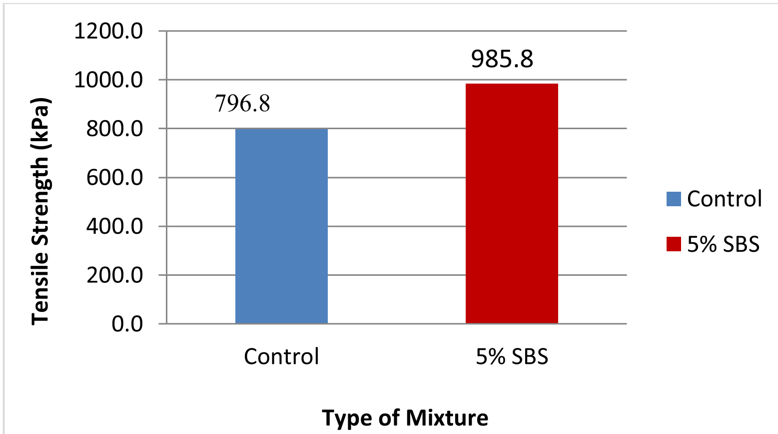

Figure 3: Comparison of tensile strength result for different mixtures

Resilient Modulus Resilient Modulus test was conducted to determine the performance of the asphalt mixture for different types of mixture. Three samples were prepared for both types of mixture. Table 2 shows the result for resilient modulus performed at the temperature of 25°C and 40°C.

Table 2 Resilient modulus for different mixtures at temperature of 25°C and 40°C

Type of mixtures	Resilient modulus (MPa) 25°C	Resilient modulus (MPa) 40°C
Control sample	1550.8	482.5
5% SBS	3329.3	615.0

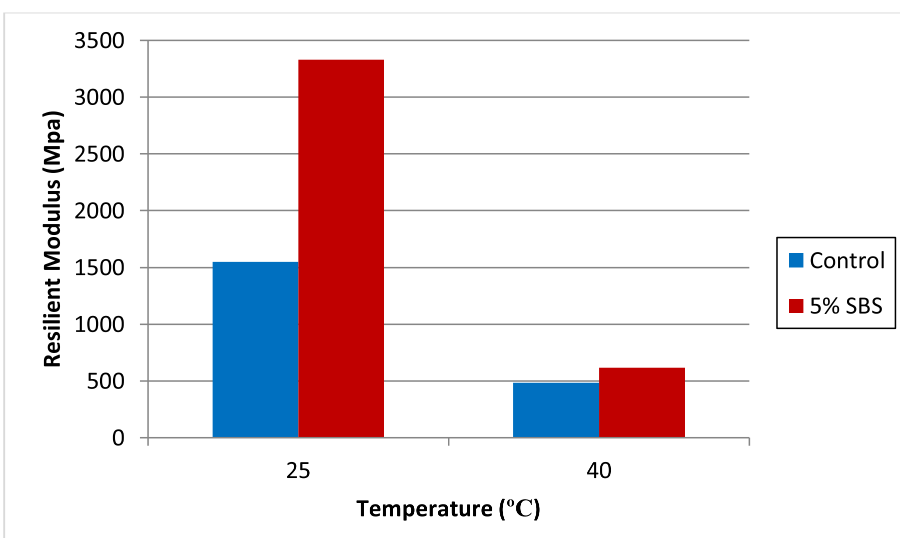

Figure 4: Comparison of resilient modulus for different mixtures at 25°C and 40°C

Figure 4 presents the comparison of resilient modulus for different mixtures at 25°C and 40°C. In general, for both mixtures, the results show that resilient modulus has largely decreases as temperature increases. The reason is due to softening of the binder sample as the temperature increased. At high temperature, the bitumen may lose its ability to bind the aggregates together, resulted in lower value of resilient modulus.

Besides that, by comparing the both types of mixtures, the modified sample has much higher resilient modulus than control sample at temperature of 25°C. This result indicates that SBS modified mixture is more prone to fatigue cracking due to its stiffness. At temperature of 40°C, the resilient modulus for SBS modified sample has slightly increased 27% than control sample. It indicates that a sample with 5% SBS additives is less susceptible to rutting.

Dynamic Creep Figure 5 displays the results of comparison between permanent strain and creep stiffness modulus of both types of mixture. Based on the result, the creep stiffness modulus of SBS modified sample was approximately higher than the control specimen. By adding 5% of SBS in asphalt mixture, the value of stiffness modulus increased with 351.6MPa. In contrast, the permanent strain value for SBS modified sample is lower than conventional mix by 50.7%. From the result, it can be observed that the addition of 5% SBS in the mixture has increases the ability of asphalt mixture to withstand the repeated load and consequently, providing higher resistance against rutting. Therefore, it is proven that the increased in stiffness modulus and reduced in permanent strain has reflected in less susceptibility to permanent deformation.

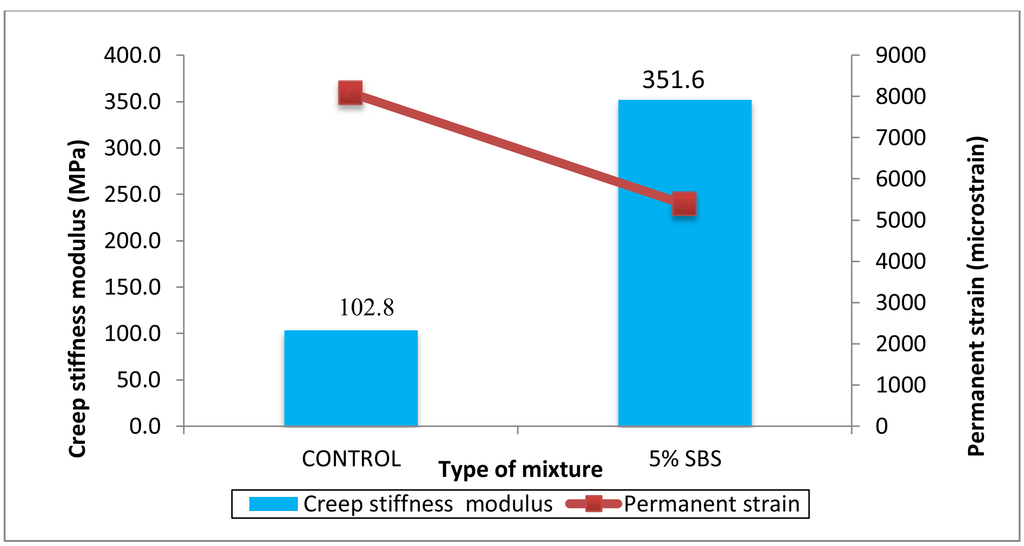

Figure 5: Comparison of dynamic creep analysis for different mixtures

Conclusion

Based on the objectives mentioned in Chapter 1, the laboratory testing and analysis data were carried out. The optimum bitumen content obtained from Marshall analysis is 5.2%. The bitumen content is accepted as it overall meets the specification of JKR/SPJ/2008 [9]. Thus, the optimum bitumen content of 5.2% will further be used in the sample preparation of samples in order to determine the performance of the conventional mix and the modified SBS asphalt mix.

From the study, it can be concluded that the addition of 5% SBS in the asphalt mixture has a significant effect on the performance of mixture. The tensile strength was seen increased as 5% SBS was added to the asphalt mixture. This indicates the modified sample has tendency to withstand larger tensile strain prior to cracking, whereby prove to be better performance than the conventional mixture. As for resilient modulus at 25ºC which investigating the performance of asphalt mixture in terms of fatigue cracking shows that the additional of SBS in asphalt mixture was prone to fatigue cracking. In contrast, result from resilient modulus at temperature of 40ºC and dynamic creep test demonstrates that modified asphalt mixture has less susceptibility to rutting, thus it reflected in higher resistance against performance deformation.

Based on the conclusions mentioned, several recommendations were mentioned to initialize some ideas for future research on performance of the modified asphalt mixture using SBS. The study on Marshall properties of SBS modified asphalt mixture should conducted to compare the result with conventional mixture. For improving the result in performance test, the various percentages of SBS in asphalt mixture should be evaluated to determine which sample results in higher performance in asphalt mixture. Apart from that, the study can be developed by determining the asphalt performance by using different types of binder such as 60/70 PEN, 80/100 PEN and PG 76.

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