Study the Performance of Modified Asphalt Mixture using Styrene Butadiene Styrene for AC10

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Abstract. Due to increase in service traffic density, the road structure have been deteriorated over a few years. Thus, in this research the conventional bitumen have been modified with Styrene Butadiene Styrene (SBS). The objective of this study are to determine the Optimum Bitumen Content (OBC) for conventional mixture and to compare the performance between SBS modified mixture with conventional mixture. During this study, various laboratory work were undertaken applying the Marshall test, Indirect Tensile Strength test, Resilient Modulus test and Dynamic Creep test. Universal testing machine (UTM) was used to determine the resilient modulus and dynamic creep of the asphalt mixture. The result shows that with additional of 5% SBS had a higher tensile strength which shows the mixtures appear to be capable of withstanding larger stresses under static loading and increased rutting resistance to rutting under repeated loading. However modified asphalt mixture prone to low temperature cracking during static loading applied. As a whole asphalt mixture using polymer performed better in rutting resistance and susceptible to low temperature cracking under static loading

Introduction

Increased traffic factors such as heavier loads, higher traffic volume, and higher tire pressure will leads to higher requirement in pavement performance. A high performance pavement requires asphalt mixture that is less susceptible to high temperature rutting or low temperature cracking. Rutting is one of the structural damage which has the longitudinal depression in the wheel part after repeated application of axial loading. Due to that, the bitumen properties should be enhance in order to get better performance of road pavement. The possible method that can be used is by modifying present bitumen properties by adding polymer as a modifier which may result in better road surface layer.

There are various modification processes and additives that are currently used in bitumen modifications, for instance styrene butadiene styrene (SBS), styrene-butadiene rubber (SBR), ethylene vinyl acetate (EVA) and crumb rubber modifier (CRM) [1]. It has been possible to improve the performance of the bituminous mixes used in the surfacing course of road pavement. Previous study [2] has point out that pavement with polymer modification exhibits greater resistance to rutting and thermal cracking, decreased fatigue damage, stripping and temperature susceptibility.

The objective of this study is to determine the Optimum Bitumen Content (OBC) for conventional mixture and to compare the performance between SBS modified mixture with conventional mixture. The study has been focused on the usage of SBS as a modifier in the asphalt mixture. The study also only involve laboratory works which consists of testing on asphalt mixture performance. Besides that, Marshall Test was conducted to determine the optimum bitumen content and its properties. In this study it will only involve Asphalt Concrete (AC10) mixture type of wearing coarse aggregate. The binders used were a conventional bitumen 80/100 pan and the amount of SBS that has been used as additive in this study was 5% of bitumen content weight since it is an optimum SBS polymer needed to add.

Previous Studies

The term 'Asphalt' is used in America whereas this same liquid binder is known as the 'Bitumen' in the UK. It is the same thing but difference in name using throughout the world. Bitumen can be define as a sticky, black and highly viscous liquid or semi-solid form of petroleum. The most primary used of bitumen is in road paving construction. It can bind and hold the other pavement component together and provide smooth and leveled surface for the moving vehicles.

Thus, to minimize the damage of the pavement surface and increase the durability of flexible pavement, the conventional bitumen need to modified. Mostly bitumen are modified using additive or replacement of polymer to improve with regards to the performance related properties such as permanent deformation and fatigue cracking [3]. In this study polymer addition is a material added to the bitumen to improve the properties and performance of the bitumen. It has been claims that the performance of asphalt pavement of polymer modified has been observed for a long time by [4]. Polymer modification of asphalt binders has become a more accepted method for addressing pavement distresses. The heavier vehicle loads, higher traffic volumes and increased tire pressures have forced user agencies to explore polymer modification for asphalt pavement application [5]. Modification of asphalt by addition of polymer results in a more elastic and durable product with greater temperature stability.

Usually, addition of polymer about 2–6% by weight can strongly enrich the binder properties and permit the building of safer roads and the reduction of maintenance costs [6]. Polymer additives are commonly added into bitumen and bituminous mixture in order to overcome the problems induced by temperature and traffic loading [7]. Since 1980s polymer modification of bitumen has been commonly performed in order to decrease bitumen susceptibility to high and low temperatures, allowing reduction in common failure mechanisms as rutting and cracking [8]. As a conclusion, polymer modified asphalt have the following benefits [9] which are improve resistance to rutting, fatigue cracking, cracking due to binder hardening, and adhesion of binder to aggregate.

Styrene Butadiene Styrene (SBS) elastomers is the most commonly used compared to other additives. The application of polymers to bitumen has been proved to help enhance performance and using polymeric materials such as styrene butadiene styrene (SBS) to the mixture has attracted the attention of both highway manufacturers and engineers to employ such materials as modifiers in asphalt mixtures recently proposed in [10]. In addition, SBS can increase the elasticity of bitumen and they are probably the most appropriate polymer for bitumen modification [11]. As modification of bitumen has widely investigated, it has been reported that it is effective in preventing thermal cracking, delaying fatigue cracking and reducing permanent deformation in hot mix asphalt at high temperature [12].

Generally, addition of SBS in the asphalt will give better performance of asphalt binder. One of the major advantage of SBS is in term of rutting and cracking issue. Previous study has reported SBS forms a highly elastic network that disappear above 100^{0}C and reforms when cooler by [13]. The deformation of pavement usually occur because of the hot temperature. The ideal binder should possess constant properties of low temperature susceptibility over the ambient temperature range, thus through the addition of SBS polymer will reduce the viscosity temperature of bitumen in the range from 0 to 100 ^{0}C that lead to increase resistance to asphalt rutting [14]. The rheological properties of road bitumen also improved when SBS modified binder exhibits higher modulus than the conventional mix, which should be beneficial with respect to permanent deformation resistance by [15].

Polymer can significantly increase the service life of highway surface [14]. On the other hands longer service life can be seen as the SBS polymer minimizes the pavement deficiencies revealed due to aging [8]. Using SBS in asphalt will increase the production cost, however the extra cost will be justified as the maintenance whole life costing is reducing after the road construction undertaken. Thus the combination of higher cost and lower maintenance tends to provide more cost effective rather that the lower cost at the initial of the construction but will need higher cost on maintenance requirement of asphalt pavement. Heavily traffic road and difficult access of road for maintenance will give more benefits as the modification of asphalt enhance better performance for longer time.

Two reasons why using of SBS polymer give more advantage. This is because polymer can strongly enhance the binder properties and permit the construction of safer road [6]. One of the significant properties of polymer modified binders is it improved adhesion and degree of cohesion which create an aggregate coating material that is expected to increase the degree of the aggregate surface roughness and produces a superior asphalt mixture [10]. Permanent and recovered strains improves as compared to unmodified binder. It could be due to the fact that the polymer-rich domains are acting as reinforcement and that bitumen rich matrix contains certain amount of polymer. In research it found that the cohesive force between asphalt and aggregate could be improved by using SBS where the flexural tensile strain is increase [16]. It has been found that polymer modified bituminous mixtures appear to possess the highest potential for successful application in the design of pavements to increase the durability and service length of the pavement or to reduce pavement layer thickness or its base thickness [10].

Methodology

The process of framework of this study is summarized as in Figure 1.

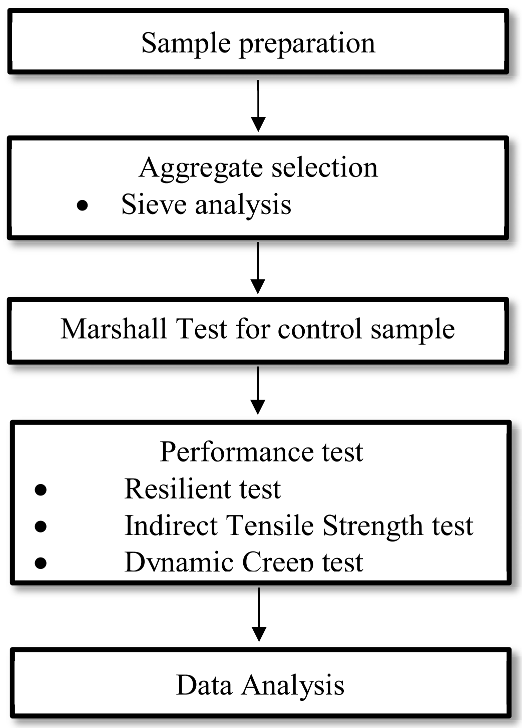

Figure 1: Research Methodology Flow Chart

Sieve AnalysisAggregate for polymer modified asphalt concrete for AC10 shall be a mixture of coarse and fine aggregates and minerals filler [9]. The aggregate used for preparing asphalt mixture were obtained from the Malaysia Rock Products Quarry, Ulu Choh. The individual aggregate shall be of size suitable for blending to produce the required gradation of the combine aggregate. In this study, median of upper limit and lower limit in the specification were chosen as the gradation limit for the samples, Figure 2 shows the aggregate gradation with median plotted that met with JKR specification [9].

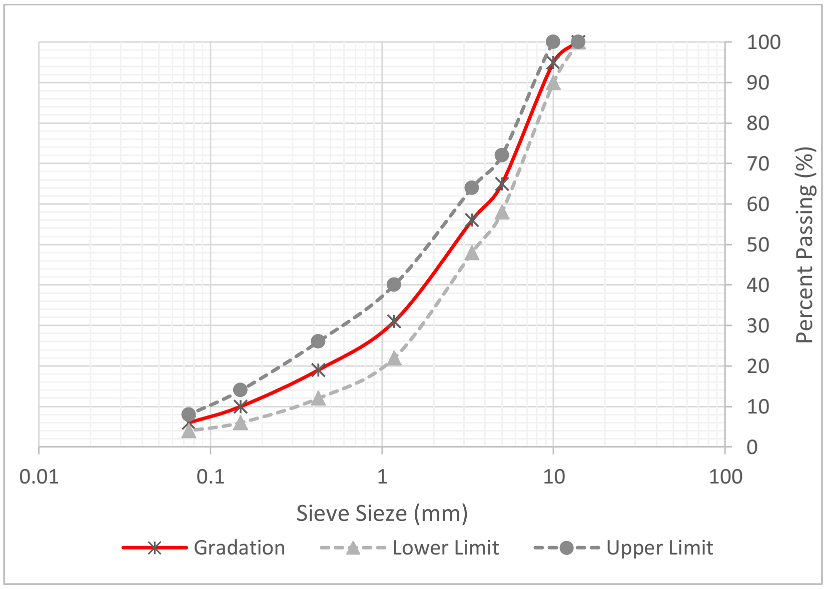

Figure 2: Aggregate gradation limit

Bitumen PreparationFor the bitumen preparation, 5% SBS polymer were added into the raw bitumen of penetration 80-100 PEN using a proper blending technique. The preparation was conducted by added gradually into the bitumen and stirred using high shear mixer with 3600-4000 rpm speed. It has been maintained with temperature 180^0C and was blending slowly about 2 hour for homogeneity of the asphalt binder.

Sample Preparation Sample with five different percentage of bitumen with an increment of 0.5% within a range of 5-7% were prepared by using a Marshall Compactor machine with 75 compaction blows on the top and bottom of specimens (10.16 cm in diameter and 6.35 cm thick).Compaction temperature and mixing temperature were designated at 140^0C and 160^0C for control sample. However for modified asphalt the compaction and mixing temperature were165^0C and 180^0C. The mixing and compaction temperatures must not exceed 180^0C in order to prevent damage in binder resulting from the excessive heating [17].

Marshall Stability TestGenerally, Marshall Test was conducted in laboratory procedure for the determination of optimum bitumen content required to be mixed with a given aggregate to produce asphalt concrete mix as outlined in JKR/SPJ/2008. Initially 15 specimens were prepared by using the Marshall Compactor. The specimens were tested for bulk specific gravity as specified in ASTM D 2726 [18]. Firstly take the mass of dry specimen in air (A), then specimens were completely submerge in the water bath at 25±1°C for 3 to 5 min and take the mass in air (C). The surface were dried and mass of specimen in air was determine (B).

$$\text{TMD} \qquad = \qquad \frac{A}{B-C}$$

Maximum theoretical specific gravity has been determined, the stability and flow tests are conducted. The specimens were immersed in the water bath at 60°C for 45 minutes. It was then place in Marshall Stability testing machine and loaded at constant rate of deformation, 51mm per minute, until failure occur. The stability result was recorded as the flow for the specimens. Besides that, theoretical maximum density (TMD) was used to determine the void in total mix (VTM) for the specimens.

The VTM was determine using the formula bellows:

$$VTM = 100 - (A / B) \times 100$$

Where:

A = Bulk specific gravity

$$= \frac{100}{\frac{P1}{SG1} + \frac{P2}{SG2} + \frac{P3}{SG3}}$$

P1, P2, and P2 = percentage of aggregate

G1, SG2 and SG3 = bulk specific gravity

B = Maximum theoretical specific gravity (TMD)

Indirect Tensile Strength TestIndirect tensile test are used to evaluate the relative quality of bituminous mixtures in conjunction with laboratory mix design testing and for estimating the potential for rutting or cracking. Standard procedure are follow as specified in ASTM D6931 [19]. This test involve loading a cylindrical specimen between two loading strips, which allow to generate a uniform tensile strength along vertical plane. Figure 3 shows the tensile strength test conducted. The tensile strength are calculated as follows:

$$S_t = \frac{2000 \times P}{\pi \times t \times D}$$

Where St is tensile strength of specimen (kPa), P is maximum load (N), t is the specimen height immediately before test (mm) and D is specimen diameter (mm).

Figure 3: The tensile strength test conducted

Resilient Modulus TestResilient Modulus is the most important parameter used in the design of pavement structures because it measure the pavement response in term of dynamic stress and corresponding strain. It also can be used in the evaluation of materials quality and as input for pavement design, evaluation and analysis due to fatigue cracking and rutting potential. The resilient modulus determine using Universal Testing Machine (UTM) as shown in Figure 4 according the procedure as specified in ASTM D4123 [20]. Six specimens with optimum bitumen content were prepared. The test were conducted at two different temperature of 25°C and 40 ± 1°C with two perpendicular rotation which is 0° and 90°. Figure 5 shows the resilient modulus test conducted.

Figure 4: Universal Testing Machine (UTM)

Figure 5: The Resilient Modulus test conducted

Dynamic Creep TestIn this study the dynamic creep test was conducted to estimate the rutting or permanent deformation potential of asphalt mix. Standard procedure are follow as specified in BS EN 12697-25 [21]. The specimens were conditioned about 3 hours and tested for dynamic creep test by using Universal Testing Machine (UTM) at 40°C with 100 kPa stress and 3600 cycles. In this test, a repeated pulsed uniaxial load was applied to the specimens and the accumulated deformation of the specimen under repeated load was measured using LVDT as shown in Figure 6. The creep stiffness modulus are calculated as follows:

$$E = \frac{\sigma}{\varepsilon}$$

Where, σ is stress and ε is permanent strain. Creep strain slope (CSS) are calculated as follows:

$$CSS = \frac{\log \varepsilon\, 3600 - \log \varepsilon\, 1200}{\log 3600 - log 1200}$$

Figure 6: The Dynamic Creep Test conducted

Data Analysis

Optimum Bitumen contentAccording to the specification, determination of optimum bitumen content for AC10 mixture were done by using several bitumen content which were 5.0%, 5.5%, 6.0%, 6.5% and 7.0%. The Marshall table was used to analyze the data obtained from the laboratory works. Table 1 shows the summary of the Marshall result.

Table 1: Summary of Marshall Result

Bitumen Content (%)	Stability	Flow	Specific Gravity	VFB	VTM	Stiffness
5.0	11577	3.73	2.263	62	6.7	3100.9
5.5	11890	3.77	2.326	78.5	3.4	3151
6.0	12485	3.78	2.332	84.5	2.4	3302.9
6.5	10604	4.02	2.331	88.9	1.8	2635.7
7.0	9452	4.56	2.251	77.1	4.5	2071.2

Graphs of stability, flow, specific gravity, VTM, VFB against bitumen contain had been plotted for determination of optimum bitumen content. The mean optimum bitumen content determine by averaging optimum bitumen content stated in [9] as follows:

I. Peak of curve taken from the bulk specific gravity.
II. Peak of curve taken from the stability.
III. VTM equals to 4.0% from the VTM.
IV. VFB equals to 75% from the VFB.

The graphs plotted for OBC determination were shown in Figure 7 - 12 bellows:

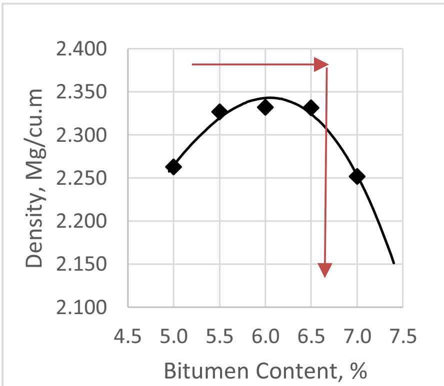

Figure 7: Graph Density versus Bitumen Content

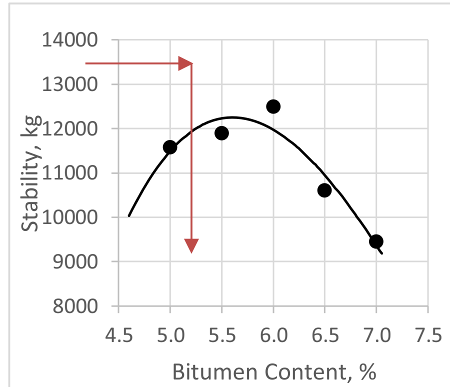

Figure 8: Graph Stability versus Bitumen Content

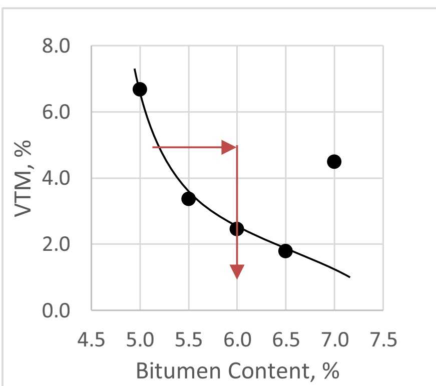

Figure 9: Graph VTM versus Bitumen Content

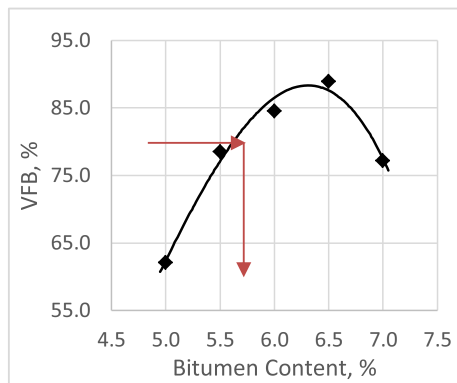

Figure 10: Graph VFB versus Bitumen Content

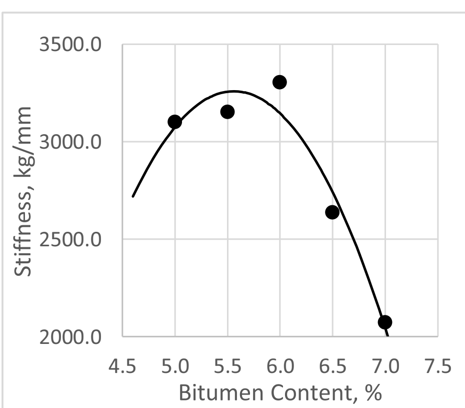

Figure 11**:** Graph Flow versus Bitumen Content

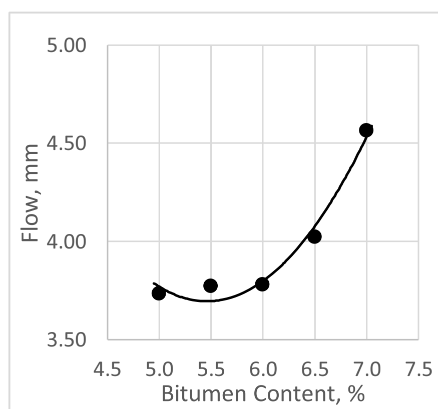

Figure 12: Graph Stiffness versus Bitumen

The optimum bitumen content obtain was 5.60 % that comply with the specification [9]. Based on the optimum bitumen content obtained, the criteria such as stability, flow stiffness, VTM and VFB were verified against the specification in [9] and presented in Table 2.

Table 2: AC10 requirements of OBC

Parameter	**Results**	**JKR Specification (JKR,2008)**	**Conformity**
Stability	12209.00	> 8000 N	Pass
Flow	3.85	2.0 – 4.0 mm	Pass
Stiffness	3175.40	> 2000 N/mm	Pass
Void in total mix (VTM)	3.00	3.0 – 5.0 %	Pass
Void filled with bitumen (VFB)	73.40	70 – 80 %	Pass

Indirect Tensile Strength TestThe typical values of the tensile strength of two mixture which is control specimen and additional of 5% SBS obtained from this study are illustrate in Figure 13.

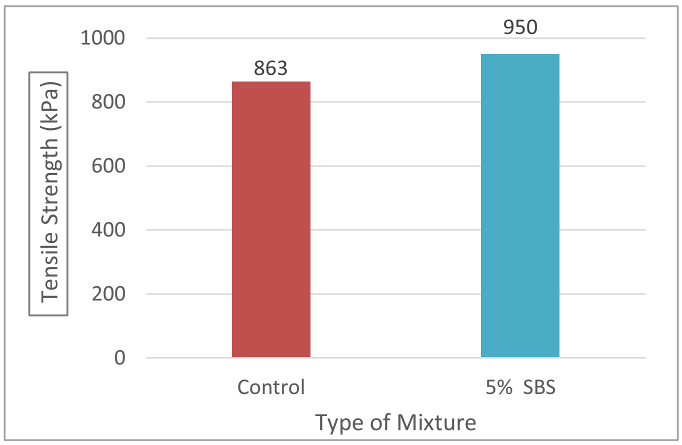

Figure 13: Tensile strength of different type of mixture

According to the graph, the tensile strength of control sample mixtures is approximately 863 kPa, whereas the mixtures containing 5% SBS have tensile strength up to 950 kPa. It appears that modified mixtures with 5% SBS increased the tensile strength for about 10%. This result is similar with the findings by [22], where 5 % SBS has led to a higher tensile strength in modified mixture. It indicates that these mixtures appear to be capable of withstanding larger stresses prior to cracking.

Resilient Modulus TestThe comparison of resilient modulus for different mixtures at temperatures of 25°C and 40 °C are shown in Figure 14.

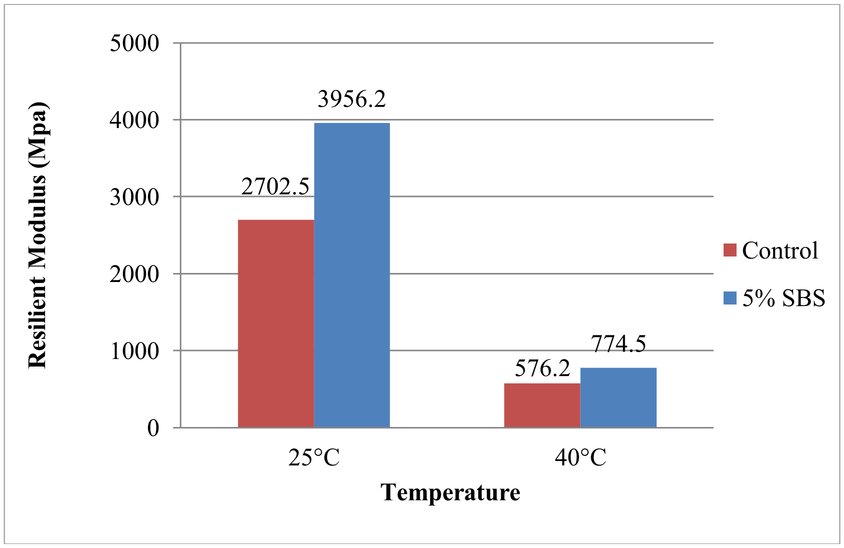

Figure 14: Comparison of resilient modulus for different mixtures at 25°C and 40°C

The graph shows that modified mixtures with 5% SBS had higher resilient modulus for both temperature at 25°C and 40°. At temperature 25°C, the 5% SBS mixture were found to have 46% increment in resilient modulus value compared to control mixture sample. Higher resilient modulus indicates increased in brittle and stiffness of the mixture, which result on reduction in resistance to fatigue as well as tendency to experience low temperature cracking under repeated loading.

At 40°C, the graph also shows increment about 34% resilient modulus for 5% SBS mixture. These result show that with regard to higher resilient modulus, the mixture have less susceptible to rutting. It can be conclude that SBS modification will obviously improve the mechanical properties of mixtures such as permanent deformation and aging.

Dynamic Creep TestFigure 15 presents the results for permanent strain, and creep stiffness modulus for two types of mixture.

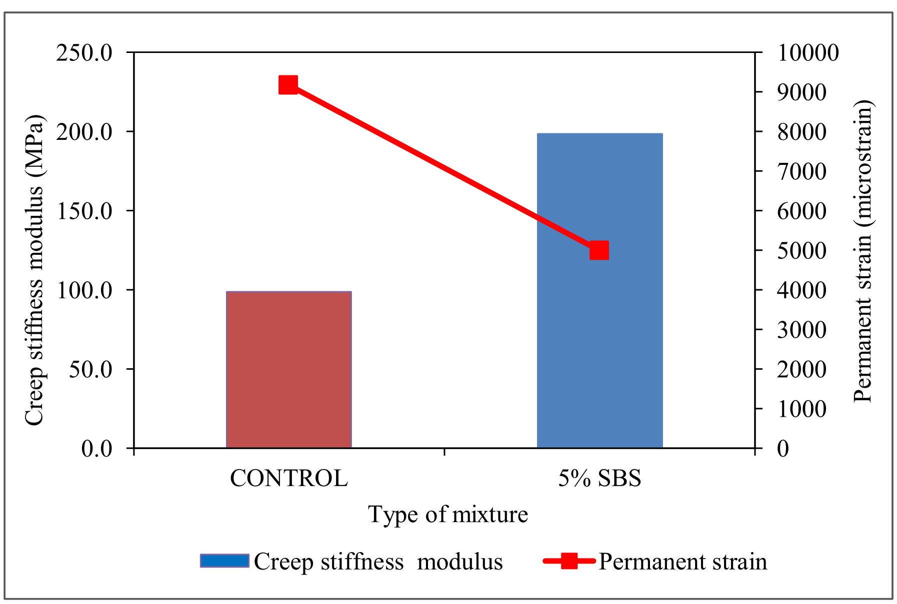

Figure 15: Dynamic creep test result

As illustrated, additional of 5% SBS evidently decrease the permanent strain at 3600 cycles. The permanent strain for 5% SBS is 4985 while for control specimens it is about two time higher which is 9163. Additional of 5% SBS perform higher creep stiffness modulus compared to control sample since it has low permanent strain. Hence it makes modified asphalt mixture using SBS have advantage in high temperature performance and reduce its temperature susceptibility [23].

Conclusion

In a nut shell, the optimum bitumen content for the mixture has been identified. The evaluation of performance on two different types of mixture of hot mix asphalt have open a significant view in improving the quality of asphalt pavement. The SBS polymer will increase the rut resistance of the hot mix asphalt as shown from the result of the Resilient Modulus Testing at 40°C and Dynamic Creep testing. Modified asphalt mixture using SBS perform better in rutting resistance and susceptible to low temperature cracking under static loading.

Based on the analysis done in, the summary of overall result and general conclusion drawn are as below:

I. The optimum bitumen content for both conventional and modified mixture is 5.6%. It comply the overall specification in [9] which is in range of 5.0% - 7.0%.
II. The tensile strength of the modified mixture with 5% SBS has increased about 10% higher than conventional mixture.
III. Modified asphalt with 5% SBS prone to be in fatigue condition under repeating load, since SBS polymer modified binder are more brittle and viscous.
IV. At 40°C in Resilient Modulus testing, modified asphalt mixture perform a good resistance to rutting which shows 34.4% higher than conventional mixture.
V. Result from dynamic creep test show that mix containing 5% SBS performed better than conventional. It conclude that some modification on binder part can strengthen the sample in term of rutting resistance.

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