

Evaluation of high temperature performance of SBS + Gilsonite modified binder

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ABSTRACT

SBS is a widely used polymer modifier for asphalt binders to improve the performance properties of hot mix asphalt. SBS is nearly indispensable when the binder properties do not satisfy the specification requirements under hot service temperatures. One of the concerns in using such additives, however, is the increased cost especially for large-sized construction projects. If a natural modifier can be used to replace some portion of industrial modifier products, such as SBS, it would significantly help reduce the cost of pavement construction. In this study, Gilsonite, a natural asphalt, is used as a binder modifier to reduce the SBS content based on a series of rheological testing. While studies on various properties of binder that is modified only by Gilsonite are common, we investigate the effect of combining SBS and Gilsonite in the same base binder. In the first phase, the binders modified individually with SBS and Gilsonite are evaluated in terms of based on the outcomes of dynamic shear rheometer and rotational viscosimeter tests. Then, the asphalt binders including both SBS and Gilsonite at different contents are subjected to the same rheological testing. The results show that around 3–4% times more Gilsonite is needed to replace 1% of SBS when the two modifiers are mixed in the same binder depending on the Gilsonite/SBS ratio selected. Besides, the viscosity of modified binders with a percent of SBS replaced with Gilsonite is always lower than that of SBS-only modified binder. It is suggested that Gilsonite can be used as an alternative modifier to reduce the cost of asphalt mixture production and compaction in the field.

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1. Introduction

The rheological behavior of asphalt binder is a very complex phenomenon, varying from purely viscous to elastic, depending on the loading time and temperature. Even though occupies only a fraction of mix volume as compared to aggregate, asphalt binder affects the whole mixture properties and thus the service performance of asphalt pavements in the field. Ideally, it is expected that binder remains flexible enough to withstand thermal stresses without cracking at low temperatures, while maintains its stiffness to withstand under high summer temperatures [1]. Binder modification offers a viable solution to overcome deficiencies arising from its temperature susceptibility, thereby improving the performance of asphalt mixtures. The best known practice in binder modification is the use of polymer modifiers to prevent excessive plastic deformations at high service temperatures by increasing the binder stiffness on the contrary, brittle fractures at low temperatures can be prevented or reduced by decreasing the binder stiffness [2]. In recent years, the most commonly used polymer modifier is the styrene–butadiene–styrene (SBS) in addition to

the other type of polymers, such as ethylene-vinyl-acetate (EVA), styrene-butadiene-rubber (SBR) and polyethylene [3]. When SBS is blended with asphalt binder, the elastomeric phase of the SBS copolymer absorbs the oil fractions and swells up to nearly nine times as much as its initial volume. Using a suitable SBS concentration, continuous polymer phase can be formed throughout the polymer modified binder (PMB), thereby significantly modifying the base binder properties [4]. The escalating cost of bitumen products and energy in addition to the lack of resources available for construction have eventually motivated the highway engineers to modify base binder properties using natural asphalts in lieu of traditional modifiers. Natural asphalts are among those alternatives which can be found in bitumen deposits, such as ‘lake asphalt’ or ‘rock asphalt’, and in different degrees of purity, i.e., the proportions of bitumen and other mineral matters. Naturally occurring bitumen deposits, generically termed as asphaltite, is the most extensively utilized bitumen resources known as Uintaite or Gilsonite in the market, which contains natural hydrocarbons with a purity of around 99%, and 57–70% of asphaltene [5]. Another unique feature of Gilsonite is to have higher nitrogen content than the oxygen in its structure, which is probably responsible for the Gilsonite’s special surface wetting properties and resistance to free radical oxidation [6]. Previous studies showed that the use of Trinidad lake asphalt and Uintaite to modify binders leads to increase in

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the complex modulus (G^*) whereas reduction in the phase angle (δ), indicating an overall improvement in the elastic response of binder [7]. Gilsonite is generally utilized to improve high temperature properties by increasing the binder stiffness; however, it may also affect the intermediate and low temperature properties of binder [8]. Gilsonite modified binders are also proved to successfully serve as an intermediate layer between aggregate and asphalt binder preventing crack initiation in asphalt concrete layers [9]. The favorable characteristics of Gilsonite becomes a good alternative to the other commercially available polymer modifiers especially in cases where high traffic volume exists under elevated temperatures during service conditions [10].

In the presented study, Gilsonite is used as a modifier to improve the high temperature performance of base (unmodified) binder. A procedure to replace a proper amount of SBS with Gilsonite is demonstrated based on the rheological evaluation of binders modified with separate and combined phases of both modifiers. The advantage of using Gilsonite in binder modification is also discussed in view of increasing mix workability and reducing the overall cost of asphalt pavement constructions.

2. Materials and method

2.1. Materials and sample preparation

Binder specimens were prepared using B 160–220 asphalt cement obtained from the Batman Petroleum Refinery of Turkey. The selected SBS polymer was Kraton D-1101 supplied by the Shell Chemicals Company. The Kraton D-1101 is a linear SBS polymer shipped in a powder form consisting of different combinations of blocks made from polystyrene (31%), and polybutadiene of a very precise molecular weight [11]. These blocks are either sequentially polymerized from styrene and butadiene and/or coupled to produce a mixture of chained blocks. Gilsonite was obtained from the American Gilsonite Company in a natural and resinous hydrocarbon form found in the Uintah Basin in the Northeastern Utah. The physical and chemical properties of the Gilsonite used are given in Table 1.

The blends of asphalt binder were produced with the selected modifiers by using a laboratory scale mixing device (Fig. 1) equipped with a four-blade impeller as shown in Fig. 2. The blends were mixed at a temperature of 180 °C and a rotational speed of 1000 rpm for 1 h.

In order to make a comparison, binder blends were prepared SBS and then tested to determine the rheological properties relevant to high temperature performance. The concentrations of the SBS Kraton D-1101 in the base bitumen were changed from 2% to 5% by weight of the base bitumen based on the outcomes of previous studies [12]. In the second phase, blends with varying contents of Gilsonite between 3% and 12% were tested to determine the same rheological properties, as in the case of testing binders using only SBS modifier. Similar sample preparation and testing procedure was also used to determine the effect of mixing Gilsonite with



Fig. 1. Laboratory scale mixing device.

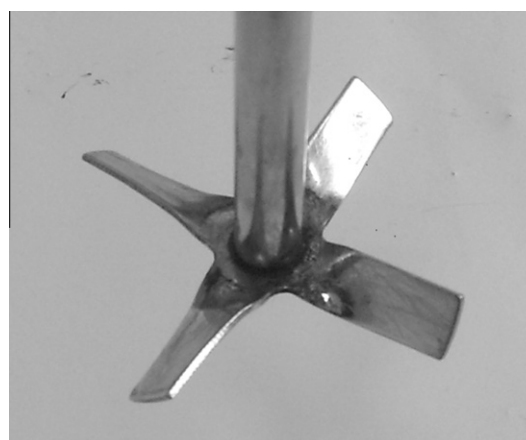


Fig. 2. Four-blade impeller.

SBS at different SBS/Gilsonite ratios. The experimental program, therefore, covered a series of rheological testing for asphalt binders modified with separate and mixed modifiers in the same blend.

2.2. Dynamic shear rheometer (DSR) test

At present, the most common method of rheological testing of asphalt binder is the dynamic oscillatory shear test, generally conducted within the region of linear viscoelastic (LVE) response. The oscillatory shear test is carried out using dynamic shear rheometer (DSR) device at different loading times (frequency) and temperatures to measure the complex modulus and phase angle, which together characterize the viscoelastic response of binder.

In this study, the rheological tests were performed by using a Bohlin DSR II rheometer under the controlled-stress conditions at temperatures varying between 52 °C and 82 °C, and 10 rad/s of

Table 1
Physical and chemical properties of Gilsonite.

Properties	Results
Penetration (0.1 mm), 100 g, 5 s	0
Softening point (°C)	126–232
Moisture content (%)	0.5
Specific gravity	1.04–1.06
Carbon (weight %)	84.9
Hydrogen (weight %)	10
Nitrogen (weight %)	3.3
Oxygen (weight %)	1.4

frequency using 25 mm diameter plate and 1 mm gap opening. The stress amplitude selected for all the test binders was adjusted to remain within the linear viscoelastic region during the rheological testing.

The principal viscoelastic parameters obtained from a DSR test are the magnitude of the complex shear modulus (G^*) and the phase angle (δ). G^* is defined as the ratio of the maximum (shear) stress to the maximum shear strain and provides a measure of the total resistance to deformation when the asphalt binder is subjected to shear loading [13]. It contains both elastic and viscous components, which are designated as (shear) storage modulus (G') and (shear) loss modulus (G''), respectively. These two components are related to the complex (shear) modulus through the phase angle (δ), which defines the time lag between the applied shear stress and shear strain responses during the oscillatory shear test.

2.3. Rotational viscosimeter (RV) test

Asphalt binders must remain sufficiently fluid or workable at high temperatures, so that the energy required during the plant mixing, laydown, and compaction phases is minimized. The rotational viscometer measures the viscosity of asphalt binder to evaluate its workability during mixing and compaction processes. The current practice is to adjust the temperature of binder such that mixing and compaction are achieved at specified viscosity levels, whether using base or modified bitumen, according to the Superpave mix design methodology. The design specification requires a viscosity level for base binders that need to be lower than 3.0 Pa.s at 135°C to maintain a reasonable level of workability, in other words, easy handling of hot mix asphalt during manufacturing and construction. In this study, Brookfield DV-III rotational viscometer was used to measure the viscosity of base and modified binders. The mixing and compaction temperatures for each combination, e.g., base binder, SBS modified, Gilsonite modified and SBS + Gilsonite modified binders, were determined based on the viscosity levels at 165 °C and 135 °C, respectively.

3. Results and discussion

3.1. Dynamic shear rheometer test results

The rheological tests using DSR were conducted to determine the high temperature properties of the base and modified binders using SBS and Gilsonite modifiers at varying percentages. The SBS content was changed from 2% to 5% and the Gilsonite from 3% to 12% when the modification to the base binder was applied separately. Binder modification using the combined modifiers was also included in the experimental program by changing the SBS and Gilsonite content together. A summary of the test configuration is given Table 2. The evaluation of the high temperature properties was done based on the Superpave asphalt binder test specifications as defined in AASHTO TP5. One of the main distresses in asphalt pavement roads is the rutting failure which depends on the high temperature properties of binder. The specification checks for the $G^*/\sin \delta$ parameter to be less than 1.0 kPa for unaged binders and 2.2 kPa for aged binders processed from the Rolling Thin Film Oven (RTFO) test simulating the aging of binder during mix production. In terms of the field performance, a binder with higher G^* and lower $\sin \delta$ is desired because it maximizes the $G^*/\sin \delta$ indicating an improved binder resistance to rutting under elevated temperatures.

The measured $G^*/\sin \delta$ for the SBS modified binders are given in Fig. 3 for the temperature range between 58 °C and 82 °C. It can be seen that the $G^*/\sin \delta$ is improved as the SBS content is increased

Table 2

$G^*/\sin \delta$ values of test binders.

Base binder	Temperature	
	58 °C	64 °C
	$G^*/\sin \delta$ (Pa)	
	801.7	372.4
<i>SBS content (%)</i>		
2	2243.7	1139.2
3	3549.5	1806.3
4	5413.7	2845.7
5	7010.3	3987.6
<i>Gilsonite content (%)</i>		
4	2206.5	944.2
5	2398.0	1080.5
6	2623.5	1232.1
7	3016.2	1416.2
8	3443.0	1631.0
9	3992.4	1895.6
10	4531.8	2146.9
11	5193.9	2447.9
12	5919.5	2793.7
14	7650.6	3545.0
<i>Combined additive content SBS–Gilsonite (%)</i>		
2–8	5647.7	2862.9
2–10	8014.9	4038.5
2–12	9529.8	5216.6
2–14	12764.1	6395.4
3–5	6810.0	3341.8
3–7	7338.6	4016.0
3–9	9067.2	4809.8
3–11	12369.2	6325.5
4–4	7725.7	3892.2
4–6	9680.8	4986.2
4–8	11067.0	5944.8
4–10	13702.3	7536.8

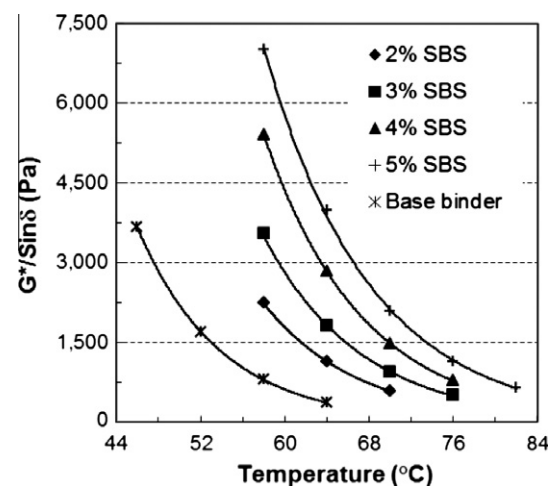


Fig. 3. $G^*/\sin \delta$ of base and SBS modified binders versus temperature.

from 2% to 5% with the largest rate of change for the 5% SBS content. The effect of using SBS can be easily observed by noticing that $G^*/\sin \delta$ of the base binder is significantly lower than that of the modified binders. Based on the Superpave PG grading system, the base binder provides 1.0 kPa of $G^*/\sin \delta$ at 55 °C, and the 2%, 3%, 4% and 5% SBS modified binders provide at 65 °C, 69 °C, 73 °C and 77 °C, respectively. Based on these temperature limits, the high temperature performance grades were found as PG-52 for the base binder, PG-64 for 2% and 3%; PG-70 for 4%; and PG-76 for 5% SBS modified binder.

Using the similar testing procedure, the $G^*/\sin \delta$ values for the Gilsonite modified binders were also determined and plotted in

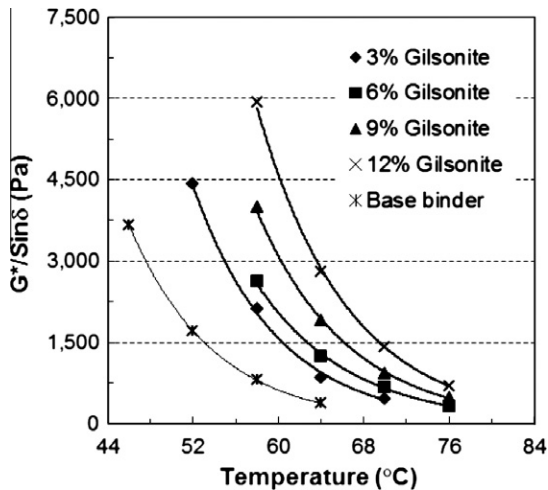


Fig. 4. $G^*/\sin \delta$ of Gilsonite modified binders versus temperature.

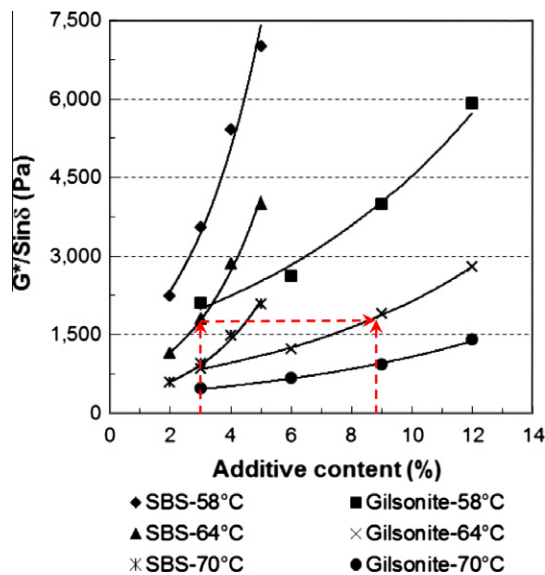


Fig. 5. Variation of $G^*/\sin \delta$ for Gilsonite and SBS modified binders.

Fig. 4 together with the base binder results. It can be seen that increasing the Gilsonite content also improves the rutting parameter, however, the amount of Gilsonite needed to achieve the same $G^*/\sin \delta$ of SBS modified binders nearly doubles. Using the measured temperature limits, the PG grades were found as PG-58 for 3%; PG-64 for 6% and 9%; and PG-70 for 12% Gilsonite modified binders.

The change in the rutting parameter for both modifiers, however, seems to be more pronounced at relatively lower temperatures. As the test temperature is increased the effect of SBS or Gilsonite modification is reduced as noticed by the slope of the trend lines. This leads to the fact that binder modification using either of these modifiers will be more effective between 58–64 °C. The effect of both modifiers can be best seen from Fig. 5 showing the $G^*/\sin \delta$ for varying amounts of SBS and Gilsonite together. It can be observed that SBS gives higher increase in the rutting parameter for the same content of modifier regardless of the test temperature used. Moreover, to reach the same $G^*/\sin \delta$ value, higher amount of Gilsonite is necessary at a given temperature as indicated by the dashed lines marking the content of both modifiers at the same $G^*/\sin \delta$.

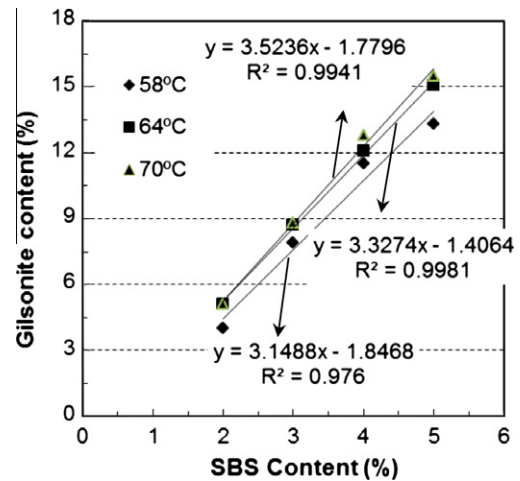


Fig. 6. Gilsonite versus SBS content to achieve the same $G^*/\sin \delta$.

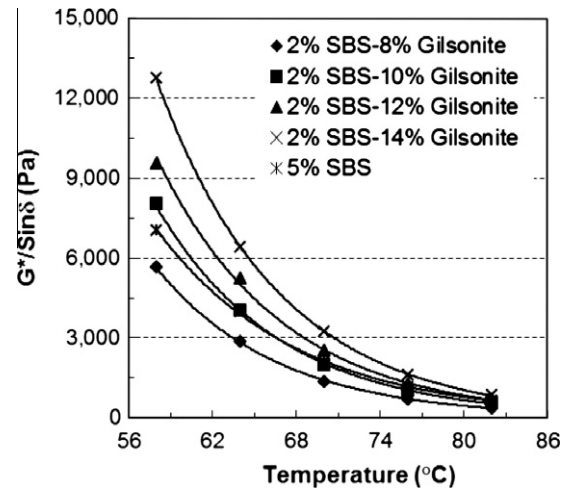


Fig. 7. Effect of Gilsonite content on $G^*/\sin \delta$ with 2% SBS.

In Fig. 6, the amount of SBS and Gilsonite contents calculated to obtain the same $G^*/\sin \delta$ are shown for three test temperatures 58 °C, 64 °C and 70 °C. It is however, interesting to note that the test temperature seems to be insensitive to replace one modifier with another. In other words, the ratio of Gilsonite/SBS content remains around 3 in spite of temperature change from 58 °C to 70 °C. It is also worth to emphasize that the fitting curves show fairly good correlations between the modifiers with coefficients of determination (R^2) better than 0.98. Based on the results of Fig. 6, it is possible to estimate the amount of SBS content that can be replaced by Gilsonite to achieve around the same $G^*/\sin \delta$. For instance, the $G^*/\sin \delta$ values for the 4% SBS modified binder was obtained by using 11.5%, 12.1% and 12.8% Gilsonite at 58 °C, 64 °C and 70 °C, respectively.

It should be noticed that the amount of Gilsonite necessary to replace the SBS content is determined using the linear relationships in Fig. 6 between the rutting parameter of each modified binder. To reduce the amount of SBS when it is combined with Gilsonite in the same blend series of rheological tests were conducted at different contents of combined modifiers and temperatures. The results of this study are given in Figs. 7–9. For comparison purposes, the $G^*/\sin \delta$ of 5% SBS modified binder was taken as a reference value to be achieved using both modifiers in the same blend of asphalt binder. The contents of SBS in the case

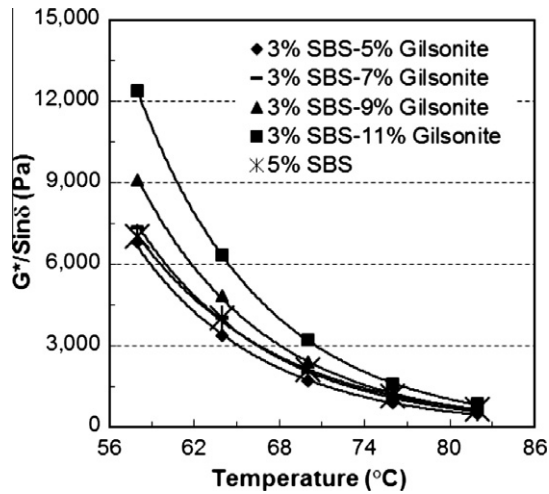


Fig. 8. Effect of Gilsonite content on $G^*/\sin \delta$ with 3% SBS.

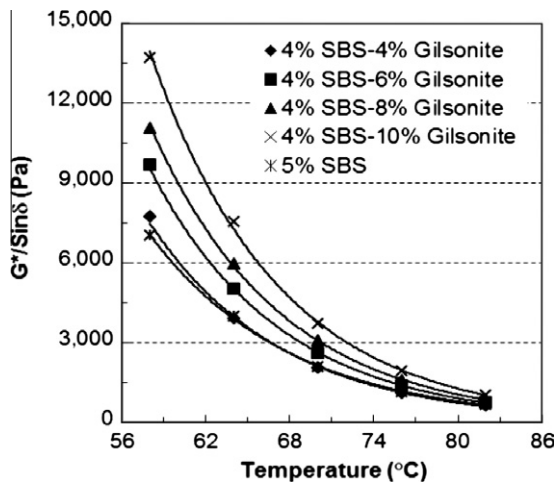


Fig. 9. Effect of Gilsonite content on $G^*/\sin \delta$ with 4% SBS.

of combined modifiers were selected at fixed percentages of 2–4%. The range of Gilsonite used was, however, adjusted based on the findings of Fig. 6 such that the Gilsonite contents can be interpolated between the selected SBS-Gilsonite combinations for the reference value of $G^*/\sin \delta$. Several trials showed that approximately 8–14% Gilsonite needs to be mixed with 2% SBS, 5–11% Gilsonite with 3% SBS, and 4–10% Gilsonite with 4% SBS to achieve the reference value. In Fig. 7, the results are given for 2% SBS with a range of Gilsonite contents between 8% and 14%. It can be seen that increasing the Gilsonite content yields higher $G^*/\sin \delta$ at all test temperatures with the largest increase at 58 °C. The selected reference value falls between the 8% and 10% Gilsonite content. Similar observations can also be made for the test binders with 3% SBS and a range of Gilsonite between 5% and 11% as shown in Fig. 8. The reference value of $G^*/\sin \delta$ is located between the asphalt blends with 5% and 7% Gilsonite contents. For blends of 4% SBS, the reference value is located slightly below the 4% Gilsonite. In general, increasing the Gilsonite content, while keeping the SBS content constant, in the same blend, increases the high temperature performance of the binder. The plotted rutting parameters in Figs. 7–9 clearly show that the effect of mixing two modifiers in the same blend is generally more pronounced between 58 °C – 64 °C.

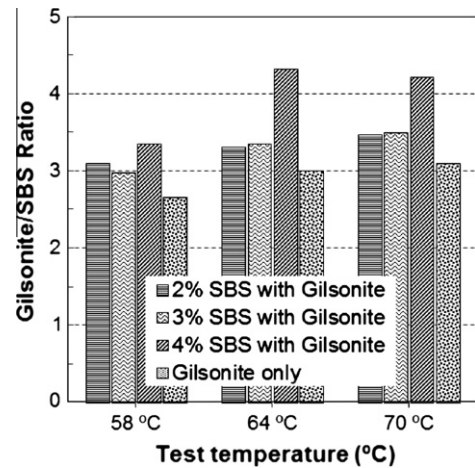


Fig. 10. Change in Gilsonite/SBS ratio for varying SBS contents and test temperatures.

The percent of SBS-Gilsonite in the same asphalt blend can be estimated using the least squares approximation method rather than using a graphical analysis for each test combination. For this purpose, least squares equation in Eq. (1) was developed to determine the best combination of SBS-Gilsonite modifiers for a selected $G^*/\sin \delta$ of SBS modified binder as a reference value.

$$\sum_{i=58}^{82} \left[\left((G^*/\sin \delta_{5\%SBS})_{T_i} \right)^2 - \left((G^*/\sin \delta_{x\%SBS+y\%Gilsonite})_{T_i} \right)^2 \right] \quad (1)$$

$x = 2, 3, 4$; and $y = 4, 5, 6, 7, 8, 9, 10, 11, 12, 14$

where x = SBS content; and y = Gilsonite content in the binder blend. The constants used in the equation, i.e., temperature range and modifier percentages, can be updated for specific test conditions to find the best modifier combination. Minimization of the above equation yields the relative percentages of both modifiers to be used in the same blend that best approximates the reference value. Based on this equation, the necessary amount of Gilsonite to achieve the reference value of $G^*/\sin \delta$ was determined and compared with the results of Fig. 5 at three test temperatures 58 °C, 64 °C, 70 °C, and 2%, 3% and 4% SBS contents. It should be remembered that the approach described in Fig. 5 relies mainly on using each modifier separately while Eq. (1) takes the effect of interaction between the modifiers into account by using them together in the same binder. In Fig. 10, the results of this comparison are given by the Gilsonite/SBS ratios for binders modified with Gilsonite only and Gilsonite-SBS together at three test temperatures. As indicated above, a reference value of $G^*/\sin \delta$ for the 5% SBS modified binder was assumed when calculating the Gilsonite/SBS ratios. The relevant Gilsonite contents from which the Gilsonite/SBS ratios are calculated for the selected reference value are listed in Table 3.

Fig. 10 displays essentially the percentages of Gilsonite that can be replaced by 1% of SBS to produce the same $G^*/\sin \delta$. It can be seen that at all three test temperatures, the binders modified with Gilsonite only gives the lowest ratios as opposed to those modified with using two modifiers together. In other words, the amount of Gilsonite to replace SBS will be less when used as a single modifier. In this case, the Gilsonite/SBS ratio is 2.7 at 58 °C, and it becomes around 3.0 for the other test temperatures. It can be noticed that the calculated ratios are also compatible with the slopes of the lines in Fig. 6. In terms of using two modifiers in the same blend, it seems that the ratios are highest for binders with 4% SBS as they range between 3.3 and 4.3. This implies that mixing Gilsonite with relatively high content of SBS lowers its effectiveness to improve the high temperature properties of binder, which evidently will

Table 3Gilsonite contents and gilsonite/SBS ratios to achieve $G^*/\sin \delta$ of 5% SBS binder.

Temperature (�C)	Gilsonite content with SBS (%)			Gilsonite only (%)
	2% SBS	3% SBS	4% SBS	
58	9.3	6.0	3.3	13.3
64	9.9	6.7	4.3	15.1
70	10.4	7.0	4.2	15.5
<i>Gilsonite/SBS ratio</i>				
58	3.1	3.0	3.3	2.7
64	3.3	3.3	4.3	3.0
70	3.5	3.5	4.2	3.1

Table 4

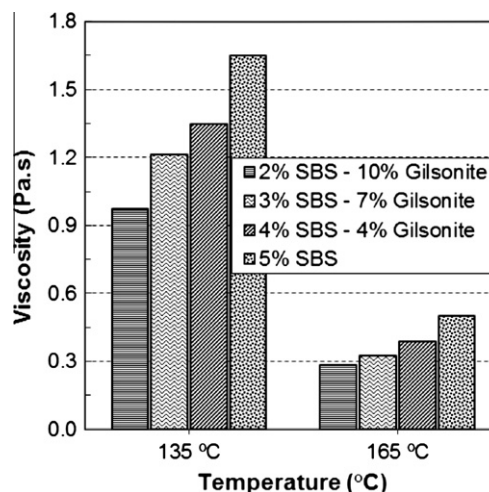
Viscosity values of test binders.

Temperature	135 �C	165 �C
	Viscosity (Pa s)	
5% SBS	1.65	0.50
<i>SBS-Gilsonite (%)</i>		
2–8	0.93	0.26
2–10	0.98	0.29
2–12	1.08	0.30
2–14	1.35	0.36
3–5	1.18	0.29
3–7	1.21	0.33
3–9	1.28	0.36
3–11	1.46	0.39
4–4	1.35	0.39
4–6	1.56	0.44
4–8	1.71	0.46
4–10	1.83	0.48

not be a viable strategy to reduce the material cost for construction. For binders with 2% and 3% SBS, the Gilsonite/SBS ratios are, however, lower than those of 4% SBS having 3.0, 3.3, and 3.5 values at 58  C, 64  C, and 70  C, respectively. In general, it can be assumed that to replace SBS with Gilsonite in the same binder around 3.5–4.0 times more Gilsonite will be required to achieve a target $G^*/\sin \delta$ of SBS modified binder. Besides, mixing a higher amount of SBS with Gilsonite seems to reduce the improvement contributed by the Gilsonite content. The unit cost of Gilsonite and SBS modifiers depends on the local conditions, such as availability, shipping distance, applicable taxes and other custom charges. Hence, a justification on the amount of saving by replacing SBS with Gilsonite is suggested to be based on the proportion of unit costs for specific locations where these materials are to be provided to the construction sector. An investigation on the cost of these materials shows that the price of 1 unit measure of SBS is nearly equivalent to 10–12 unit measure of Gilsonite. If, as stated in the above section, 1% SBS is replaced by 4% Gilsonite then the total cost of modifiers, hence the construction, will be reduced by a factor of 2.5 to 3.0 (250% to 300%). For a typical pavement construction, this will be clearly a substantial saving to be considered when Gilsonite is selected as an alternative modifier to SBS. It is, however, suggested that, a separate experimental program should be furnished to determine the intermediate and low temperature properties of Gilsonite modified binder if the construction site is likely to reach low temperatures.

3.2. Rotational viscosimeter test results

The viscosity of modified binders was also investigated at different percentages of Gilsonite-SBS contents together. As for the complex modulus tests, the viscosity of 5% SBS binder was selected as a reference value to compare with those of binders with the

**Fig. 11.** Viscosity of modified binders with varying Gilsonite-SBS contents.

combined Gilsonite and SBS modifiers. The measured viscosity values for all the modifier combinations are listed in Table 4.

To evaluate the effect of combined modifiers, some of the results are shown in Fig. 11 for 135  C and 165  C, in which the SBS-Gilsonite combinations are changed as 2–10%, 3–7% and 4–4% with the Gilsonite/SBS ratios of 5.0, 2.3, and 1.0, respectively. It can be seen that the 5% SBS modification yields the highest viscosity at both temperatures as compared to the other binders prepared by the combined modifiers. It is interesting to note that even in the case of Gilsonite/SBS ratio of 5.0, the viscosity still remains lower than that of 5% SBS binder. This indicates that mixing a high content of Gilsonite with SBS can produce a lower viscosity of combined binder, which results in lower energy consumption during both manufacturing and compaction process. In this sense, the partial replacement of SBS with Gilsonite seems to be a feasible alternative to reduce the cost of materials and pavement construction.

4. Conclusions

In this paper, an evaluation of using Gilsonite and SBS modifiers is presented according to the rheological properties relevant to high temperature performance. The study is carried out based on a number of rheological tests using each modifier separately and combined in the same base binder. The testing program included measuring $G^*/\sin \delta$, and viscosity values at two test temperatures to characterize binders in terms of rutting performance, and workability characteristics. Analysis of data obtained from the testing program yields the following outcomes:

- It was shown that increase in Gilsonite content yields higher $G^*/\sin \delta$, however, the rate of increase is generally lower as compared to the case of SBS modified binders.

- When comparing two modifiers separately, SBS yields higher $G^*/\sin \delta$ than Gilsonite does at any selected test temperature. This means that the improvement in high temperature performance is more significant when using SBS modifier.
- When the two modifiers are mixed in the same binder, approximately 3.0–4.0% Gilsonite is needed to replace 1% of SBS, depending on the Gilsonite/SBS ratio used. It was also found that the required amount of Gilsonite in the case of combined modifiers is relatively insensitive to the ratio of Gilsonite/SBS. This is also true when calculating the necessary amount of Gilsonite whether mixed with SBS or used separately in the base binder.
- In terms of high temperature performance, the improvement between 58°C – 64°C seems to be more effective for both modifiers as the rate of increase in $G^*/\sin \delta$ is generally highest. For temperatures higher than this range, the relative improvement is usually negligible. Therefore, it is suggested that these temperature limits be considered when the amount of Gilsonite is to be determined to replace the SBS content.
- The results showed that using Gilsonite with SBS in the same blend can reduce the viscosity of binder even at Gilsonite/SBS ratios ranging from 1.0 to 5.0. The reduction in the binder viscosity will help increase the workability of asphalt mixture during manufacturing and reduce the compaction energy, which, in turn, will reduce the overall cost of pavement construction.

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