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Investigating the Influence of SBS and Gilsonite on the Rheological Properties of Asphalt Binder Using Statistical Analysis

Danial Mirzaiyan, Amir Amini, Farhang Jalali
a. Ph.D. student, College of Engineering and Physical Science, University of New Hampshire (UNH), Durham, New Hampshire. United States
b. Ph.D. student, School of Civil Engineering, Iran University of Science and Technology (IUST), Tehran, Iran.
c. National Center for Asphalt Technology at Auburn University, 277 Technology Pkwy, Auburn, AL 36830, Tel: 334-332-6620

***Abstract**: In this study, Gilsonite and styrene-butadiene-styrene (SBS) binder modifiers effects on the asphalt binders' properties performance and temperature susceptibility are investigated. For the purpose of this study different tests like dynamic shear rheometer (DSR) and bending beam rheometer (BBR) were implemented. Moreover, Gilsonite and SBS effect on temperature susceptibility and rheological aging index of the binders was examined through TS and RIA indexes measurement. At the end, in order to investigate the Gilsonite and SBS effects on asphalt binders' physical properties and temperature susceptibility, the ANOVA and Tukey tests were applied. The results showed that addition of Gilsonite and SBS to asphalt binders improved performance characteristics and decreased temperature susceptibility and rheological aging of the modified binders.Moreover, the results of ANOVA test revealed that modifiers dosage and test temperature have an effect on temperature susceptibility and asphalt binders PG temperature and BBR test parameters when using a 0.95 significance level.*

***Keywords**: modified asphalt binder, temperature susceptibility, rheological aging index, Analysis of variance, Tukey test*

I. Introduction

The asphalt binder constitutes only part of the mix volume, it can affect the entire mixture properties and thereby the performance of the asphalt used in pavements and roads (Herrington et al., 1999). To overcome the disadvantages of binders that have roots in its possibility of losing functionality in adverse temperature, a feasible solution could be the utilization of binder modification techniques to enhance the properties of asphalt mixture and thereby its functionality (Airey, 2002). For this purpose, a number of polymer modifiers have been developed during the recent decade that proves effective in improving the performance and temperature properties of binders; binder modifiers like styrene–butadiene–styrene (SBS), recycled polymers such as crumb rubber modifier (CRM) and nanomaterials, to name but a few (Airey, 2004, Amini et al., 2017, Goli et al., 2017).

A number of researches have been undertaken in recent years on the impacts of SBS polymer and Gilsonite on performance properties of asphalt binders and mixtures (Ameri et al., 2018, Sabouri et al., 2018, Ziari et al. 2016).In a study undertaken by Ahmedzade et al. (2007) the indirect tensile fatigue test (ITFT) was used for investigating the SBS effect on the asphalt mixtures' fatigue response. They concluded that adding SBS to mix was effective in enhancing the fatigue behavior of binder (Ahmedzade et al., 2007). The SBS modified mixes were examined in terms of fatigue resistance in other study conducted based on dissipated energy concept. In this study, the fatigue resistance of the modified mix designs was significantly improved compared with the test specimen (Hamed, 2010). Esfeh et al concluded that the addition of Gilsonite to asphalt facilitates the viscosity, decreases the penetration, and stiffens the binder (Esfeh et al., 2011). Ameri et al. and Feng et al. in separate studies concluded that Gilsonite modified binders showed an improved response at high as well as intermediate service temperatures (Ameri et al., 2011b, Feng et al., 2011). An improvement in moisture damage resistance for binders modified with Gilsonite was also reported by Feng et al (Feng et al., 2011).

This study is aimed at investigating the Gilsonite and SBS modifiers' effect on binders' performance, temperature susceptibility and rheological aging. Moreover, the above factors' effect on the binder properties modified using Gilsonite and SBS were statistically evaluated. Additionally, the ANOVA method was used to identify significant parameters and Tukey test was used for investigating the interaction between the modified binders' main factors.

II. Experimental

2 .1. Materials

This study used PG 64-22 asphalt binder. Table 1 shows the asphalt binder physical properties. Also, we used the SBS polymer LG501.The physical properties of SBS polymerwas shown in the Table 2.Finally, the Gilsonite used in this study was supplied by Kardust Aria Company, extracted from the mine located in Gilan-e-Gharb, Kermanshah Province of Iran. Table 3 represents the Gilsonite physical properties.

Table 1. Base binder's physiochemical properties.

Aging states	Test properties	Test result
Unaged asphalt binder	Penetration @ 25 °C (0.1 mm)	64
	Softening Point (°C)	49.8
	Viscosity @ 135 °C (Pa.s)	0.376
	G*/Sin(δ) @ 1 (KPa)	65.5
RTFO aged residual	G*/Sin(δ) @ 2.2 (KPa)	64.5
RTFO + PAV aged residual	G*.Sin(δ) @ 5000 (KPa)	17.2
	S-value @ 300 (MPa)	-14.81
	m-Value @ 0.3	-12.21
	PG Continuous Grade	64.5-22.2
	PG Category	64-22

Table 2. SBS physical and mechanical properties.

Properties	Specification	Test Method
Density (g/ cm^3)	0.94	IS0 2781
Volatile Material (Wt.%)	Max. 0.5	ASTM D1416
Styrene Content (%)	31	LSYQS1D0111
Melt Index (g/10min)	<1	ASTM D1238
Hardness (Shore A)	79	ASTM D2240
T.S.V (cst)	13.4	ASTM D445

Table 3. Physical properties and elemental analysis of Gilsonite

Parameters measured	Specification	Test method
Specific gravity @ 25 ºC (g/cm3)	1.05	ASTM D3289
Solubility in CS2 (%)	99	ASTM D4
Solubility in TCE (%)	96	ASTM D2042
Penetration @ 25 ºC (0.1 mm)	0	ASTM D5
Ash content (%)	2.24	ASTM D3174
Moisture content (%)	0	ASTM D3173
Carbon content (%)	85.22	ASTM D5291
Hydrogen content (%)	6.43	ASTM D5291
Nitrogen content (%)	0.77	ASTM D5291
Oxygen content (%)	1.59	ASTM D5291
Sulfur content (%)	3.09	UOP 864

2.2 Modified asphalt binder preparation

The Gilsonite of different dosages amounting to 4%, 8%, and 12% of the asphalt binder were added to the base binder after sieving through no.50 (0.2 mm) sieve. Subsequently, the mix was heated up to 140 ºC and was stirred up in a mixer for 150 min with the speed 150 rpm. In the next step, the mixture was warmed up further to 180 ºC for more 30 minutes at the stirrer speed of 4500 rpm for it to attain homogeneity (Ameri et al., 2011a). Also, the asphalt binder was heated up to 180 ºC and the SBS in 3%, and 5% by weight of the binder was added to the base binder and stirred for 60 min at 4000 rpm in a high shear mixer.

2.3 Method

In this study a number of tests including dynamic shear rheometer (DSR) and bending beam rheometer (BBR) tests were performed to analyze the neat and modified properties; After preparing samples using rolling thin film oven (RTFO)(ASTM-D2872, 1997) and pressure aging vessel (PAV)(ASTM-D6521, 2003), a number of tests were performed on Superpave performance grading specification(ASTM-D6373, 1999).Based on the ASTMD2872 standard regarding mitigating the rutting performance, the G*/ Sin (δ) at high temperatures in respect with the unaged binder and aged binder after performing the test rolling thin film oven (RTFO) should be more than 1 kPa and 2.2 kPa respectively (Bai and Allaoui, 2003). The BBR test was conducted at -6 to -24 ºC to study binder characteristics at low temperatures, leading to low temperature cracking(ASTM-D6648, 2001). The binder stiffness and the change in the rate of stiffness variation with time (m-value) at 60 s loading were two parameters obtained through this test (Chen and Huang, 2007).

2.4 Statistical analysis

In addition, using ANOVA can efficiently predict the effect of factors on the test results at the level of significance of α = 5%. In the present study, the modifiers dosageand test temperature constituted the main factors of analysis. The Tukey test was used for the means comparison with 0.05 level of significance. Tukey's test includes single-step multiple comparison procedures together with a statistical test. The above test can compare all possible pairs of means based on a Studentized range distribution (*q*) (Bayekolaei et al., 2016).

III. Results

3.1 Effect of SBS and Gilsonite on High and Low temperature

Investigation of the effect of SBS and Gilsonite on G* and phase angle before and after RTFO aging process has been shown in Table 4. In this paper, these parameters for all samples at temperatures of 70 ºC have been evaluated. The results show that with increasing the percentage of modifiers, G* increase and phase angle decrease. The results of DSR test in term of high and low temperature continuous grade for asphalt binders have been shown in Table 4. From this Table, it can be seen that adding SBS and Gilsonite to the neat binders will lead to an increase in HT continuous grade. This trend continues to exist as an amount of modifiers increase.For investigation of the effect of SBS and Gilsonite on the binders LT performance, BBR test was conducted on modified and unmodified binder. As it is observed in Table 4 adding SBS and Gilsoniteto neat binders cause an increase in LT of asphalt binder.

Table 4. The Effect of Modifiers on G*, Phase angle before and after Aging Process and Binders PG.

Sample code	Before RTFO aging		After RTFO aging		HT Continuous grade	LT Continuous grade	Performance Grade
	G* (kPa)	Phase angle (degree)	G* (kPa)	Phase angle (degree)			
Neat binder	0.479	86.3	1.06	84.2	64.5	-22.2	PG 64-22
SBS3	1.42	79.5	2.83	75	72.9	-19.7	PG 70-16
SBS5	2.36	73	5.22	68.1	78.5	-18.4	PG 76-16
Gil4	0.849	84.9	2.08	81.4	69.1	-19.0	PG 64-16
Gil8	1.26	83.2	3.11	79.3	72.4	-16.4	PG 70-16
Gil12	2.65	79.4	7.44	74.5	79.8	-12.9	PG 76-10

In Fig.1 (a) and (b) it can be seen that in temperatures of 58 °C, G*/sin δ increases with increasing the modifiers content. The slope of this behavior goes sharper for Gilsonite modified binders. As the temperature increase, both the slope of this trend and G*/sin δ values will be reduced. In Fig. 1 (c) one can understand that stiffness goes higher with increasing modifiers dosages and significantly decline with increases in temperature. On the other hand, Fig. 1 (d) shows that as temperature goes higher the m-values will be more. With increasing the Gilsonite dosage, the slope of changing the m-value with temperature will be slightly reduced. The exact kind of behavior like binders modified with Gilsonite in figure (c) and (d) has been shown in Fig. 1 (e) and (f) for SBS modified binders.

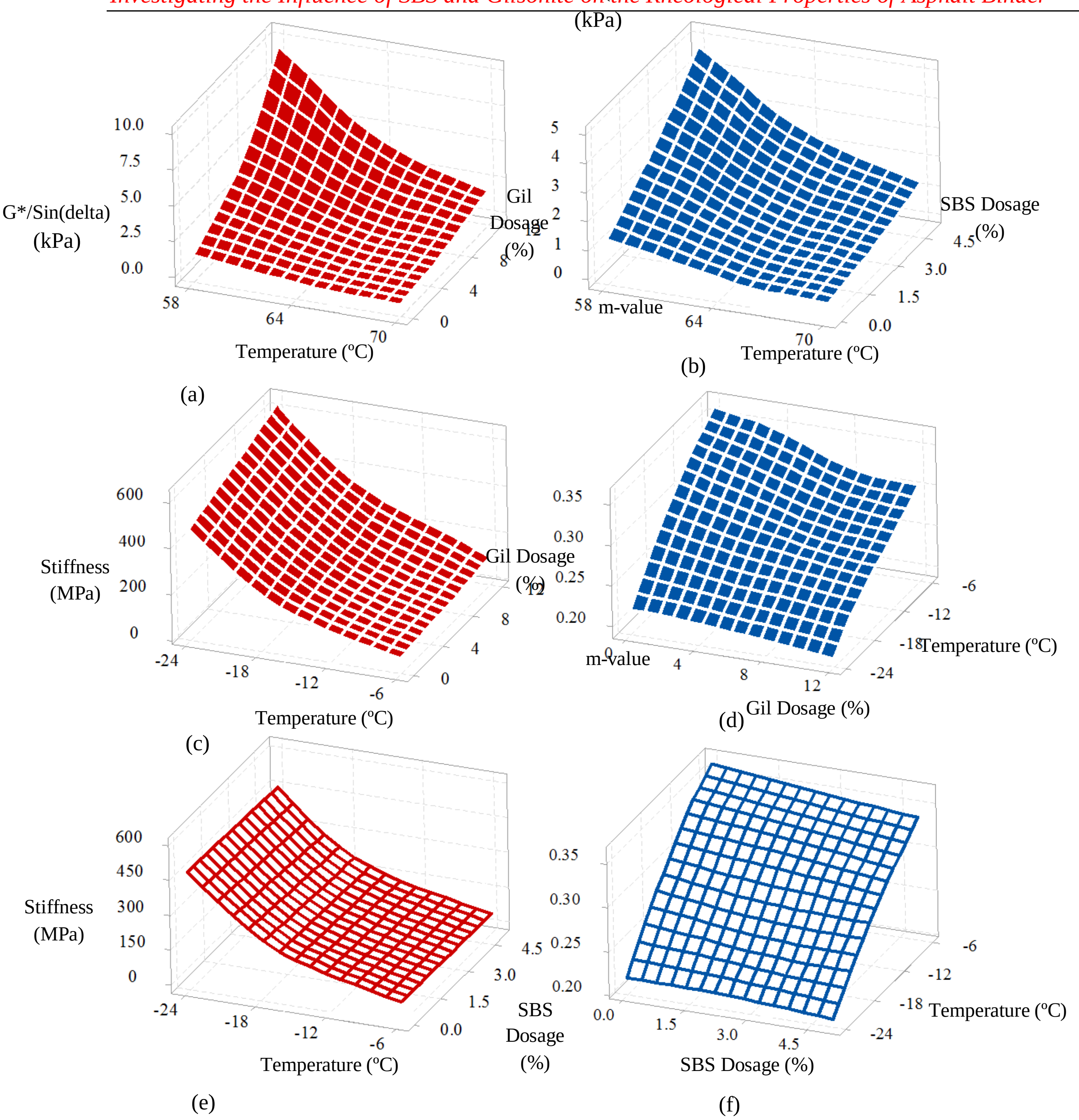


Figure 1. Surface Plot of the Effects of SBS, Gilsonite and Temperature on PG Temperature of the Asphalt Binder.

3.2 Effect of SBS and Gilsonite on temperature susceptibility and rheological aging

Temperature susceptibility is regarded one of the most important rheological properties of any modified asphalt binder, relating to its final performance concerning permanent deformation (Wang et al., 2009). Lower temperature susceptibility of an asphalt binder guarantees the enhanced performance of the pavement in adverse high temperatures (Fromm and Phang, 1971).To calculate the high-temperature susceptibility of each individual binder the Eq. (1) was used.

Where G^*_1 and G^*_2 are the binders' rheological parameters in Pascal and T_1 and T_2 are in Kelvin.

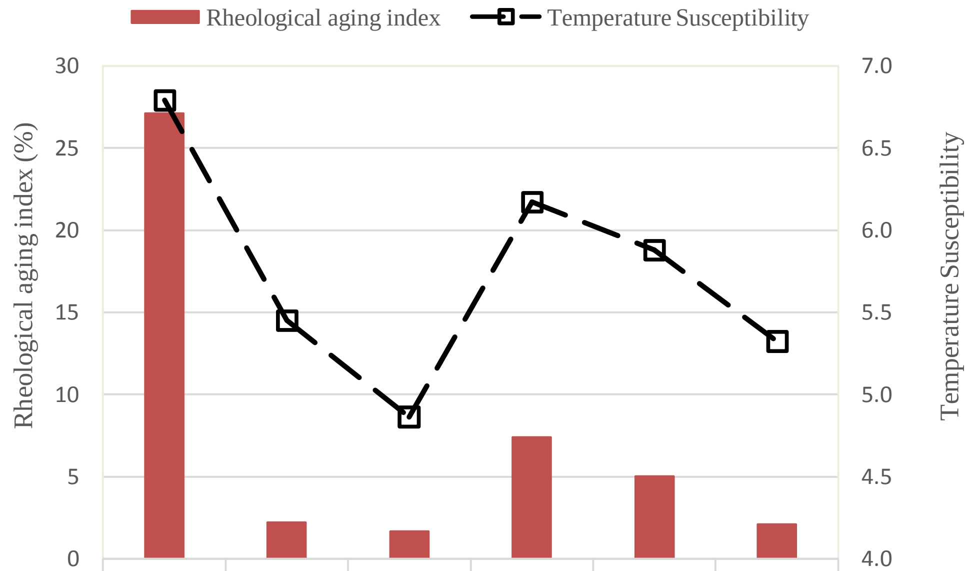
$$\mathrm{TS} = \frac{\log\log(G_1^*) - \log\log(G_2^*)}{\log(T_2) - \log(T_1)} \quad \textbf{Equation 1}$$

The DSR test was conducted in order to theinvestigation of aging susceptibility for modified binders. The data were collected at 70°C and 10 rad/s. The results were used to determine the rheological aging index according to Eq.(2)(Fini et al., 2016).

$$RAI = \frac{G^{*}{}_{aged}}{G^{*}{}_{unaged}} \times e^{(\delta_{aged} - \delta_{unaged})} \qquad \text{Equation 2}$$

Where G*has already been introduced.δparameter is the phase angle of the samples. The aged and unaged subscripts refer to aged and unaged samples, respectively.

Using Eq. (1) the TS of the Gilsonite and SBS modified binders was calculated considering the relevant parameters of rutting at two largely different temperatures of 58°C and 76 °C and at 1.56 Hz frequency. Moreover, the results of RAI was calculated by Eq. (2). As shown in Fig. 2 the TS and RAI decrease with adding SBS and Gilsonite to the neat binder. It can be revealed from the results that SBS has higher effects on decreasing in TS and RAI than Gilsonite.



	Neat	SBS3	SBS5	Gil4	Gil8	gil12
Rheological aging index	27.10	2.21	1.65	7.40	5.00	2.09
Temperature Susceptibility	6.79	5.45	4.86	6.17	5.88	5.32

Figure 2. The Effect of Modifiers on Binders Temperature Susceptibility (TS) and Rheological Aging Index (RAI).

3.3 Statistical analysis results

In this study, the null hypothesis consists of the mean of individual properties between temperature susceptibility, HT continuous grade, LT continuous grade, stiffness and m-value in BBR test, G*/sinδ and, modifiers dosage and temperature range are equal; Also different set of means constitute the alternative hypothesis.To evaluate the effect of the binders'modification on the temperature susceptibility, HT and LT continuous grade and binder modification and test temperature on the G*/sin δ, stiffness and m-value in BBR test, the two-way ANOVA was used with a confidence coefficient of 95% (α = .05). The ANOVA results for temperature susceptibility, HT and LT continuous grade and PG temperature span are shown in Table 5. The p-Value for each response in this table is less than 0.05. It can be deduced from these results that Gilsonite and SBS modifiers can affect these parameters.

Table 5. The Effect of Gilsonite and SBS Dosages on Temperature Susceptibility and PG Temperature of Asphalt Binders using the ANOVA Test.

Effective parameter	Variable	SS	MS	F-Value	p-Value	Acceptance

Gilsonite modified binders						
Gilsonite dosages	Temperature Susceptibility	3.26	1.09	14.7	2.68E-02	Accept
	HT Continuous grade	284	94.7	96.2	1.77E-03	Accept
	LT Continuous grade	82.3	27.4	149	9.23E-04	Accept
	PG Temperature span	65.9	22	31.9	8.93E-03	Accept
SBS modified binders						
SBS dosages	Temperature Susceptibility	5.56	2.78	39.8	2.45E-02	Accept
	HT Continuous grade	198	98.8	759	1.32E-03	Accept
	LT Continuous grade	11.2	5.59	51.9	1.89E-02	Accept
	PG Temperature span	115	57.5	382	2.61E-03	Accept

According to Table 6, the results indicate that modifiers dosages *p* values for G*/sin δ (1.8E-04, 4.7E-03 for Gilsonite and SBS respectively), stiffness (7.0E-10, 1.2E-02 for Gilsonite and SBS respectively) and m-value for Gilsonite (1.4E-09) and SBS (2.1E-02) are less than .05. Which means that this factor for all of them are significant. The *p* values for temperature for G*/sin δ (7.3E-05, 6.7E-24 for Gilsonite and SBS respectively), stiffness (8.1E-24, 7.3E-15 for Gilsonite and SBS respectively) and m-value for Gilsonite (5.1E-20) and SBS (1.7E-03) are less than .05 as well. Which also indicates that temperature is significant for these responses.

Table 6. The Effect of Modifier Dosages and Temperature on G*/sin δ and BBR Test Parameters using the ANOVA Test

	Modifier dosage				Test temperature			
	SS	MS	F-Value	p-Value	SS	MS	F-Value	p-Value
Gil modified binders								
G*/Sin (delta)	9.6E+01	3.2E+01	1.2E+01	1.8E-04	9.3E+01	4.6E+01	1.8E+01	7.3E-05
Stiffness	6.2E+04	2.1E+04	4.4E+01	7.0E-10	1.1E+06	3.5E+05	7.5E+02	8.1E-24
m-value	7.6E-03	2.5E-03	4.1E+01	1.4E-09	6.7E-02	2.2E-02	3.6E+02	5.1E-20
SBS modified binders								
G*/Sin (delta)	3.5E+01	1.7E+01	8.7E+00	4.7E-03	6.0E+05	2.0E+05	3.5E+03	6.7E-24
Stiffness	6.7E+02	3.4E+02	5.8E+00	1.2E-02	6.2E-02	2.1E-02	3.0E+02	7.3E-15
m-value	6.8E-04	3.4E-04	4.9E+00	2.1E-02	4.5E+01	2.3E+01	1.1E+01	1.7E-03

To compare means with an alpha level set at .05, the Tukey's test was used. According to Table 7, the results indicate that for temperature susceptibility there is a significant difference between the means of SBS from 0% to 3%, 0% to 5% and vice versa and Gilsonite dosages from 0% to 8%, 0% to 12% and vice versa. It means that addition of 3% and 5% SBS and 8% and 12% of Gilsonite to neat binder have a major effect on temperature susceptibility. On the other hand, the addition of 2% SBS to 3% SBS modified binders and 4% of Gilsonite to 8% Gilsonite modified binders does not have an influence on this response. It also shows the significant difference between the means of all dosages of Gilsonite and SBS for HT continuous grade. The results for the LT continuous grade show a significant difference between the means of SBS dosages from 0% to 3% and 0% to 5% and vice versa and all dosages for Gilsonite. It reveals that except SBS dosages from 3% to 5% and 5% to 3%, the other percentage of SBS and Gilsonitehave a significant effect on LT performance.

Table 7. Mean Comparison of TS, HT and LT Continuous Grade for Modifiers Dosages by using the Tukey Test.

Variable	SBS modified binders				Gil modified binders			
	Variable levels	Mean Difference	Sig.	95% Confidence Interval	Variable levels	Mean Difference	Sig.	95% Confidence Interval

					Lower Bound	Upper Bound					Lower Bound	Upper Bound
Temperature Susceptibility (TS)	0	3	1.59	4.7E-02	0.04	3.16	0	8	1.36	4.5E-02	0.05	2.68
		5	2.29	2.4E-02	0.74	3.86		12	1.66	2.6E-02	0.35	2.98
	3	0	-1.59	4.7E-02	-3.16	-0.04	8	0	-1.36	4.5E-02	-2.68	-0.05
		5	0.70	2.1E-01	-0.86	2.26		12	0.30	7.2E-01	-1.02	1.61
	5	0	-2.29	2.4E-02	-3.86	-0.74	12	0	-1.66	2.6E-02	-2.98	-0.35
		3	-0.70	2.1E-01	-2.26	0.86		8	-0.30	7.2E-01	-1.61	1.02
Continuous HT grade (°C)	0	3	-8.02	3.7E-03	-10.00	-5.90	0	8	-9.59	7.2E-03	-14.00	-4.80
		5	-14.01	1.2E-03	-16.00	-12.00		12	-16.37	1.5E-03	-21.00	-12.00
	3	0	8.02	3.7E-03	5.90	10.00	8	0	9.59	7.2E-03	4.80	14.00
		5	-5.99	6.6E-03	-8.10	-3.90		12	-6.79	1.9E-02	-12.00	-2.00
	5	0	14.01	1.2E-03	12.00	16.00	12	0	16.37	1.5E-03	12.00	21.00
		3	5.99	6.6E-03	3.90	8.10		8	6.79	1.9E-02	2.00	12.00
Continuous LT grade (°C)	0	3	-2.08	4.4E-02	-4.00	-0.15	0	8	-6.32	2.1E-03	-8.40	-4.30
		5	-3.31	1.8E-02	-5.20	-1.40		12	-8.40	8.9E-04	-10.00	-6.30
	3	0	2.08	4.4E-02	0.15	4.00	8	0	6.32	2.1E-03	4.30	8.40
		5	-1.23	1.2E-01	-3.20	0.70		12	-2.08	4.9E-02	-4.20	-0.01
	5	0	3.31	1.8E-02	1.40	5.20	12	0	8.40	8.9E-04	6.30	10.00
		3	1.23	1.2E-01	-0.70	3.20		8	2.08	4.9E-02	0.01	4.20

Results of means comparison analysis using the Tukey's test for the effect of SBS and Gilsonite dosages on stiffness, m-value and G*/sin δ in significance level as high as 0.95 are presented in Table 8. This Table presented the significant differences between changing SBS percentage from 0% to 3% and 0% to 5% and vice versa and all dosages of Gilsonite for stiffness in BBR test. It means stiffness is affected by all amounts of modifiers except adding 2% SBS to 3% SBS modified binders. Data analysis of Table 8 indicates that the differences between SBS dosages from 0% to 5% and 5% to 0% are not significant for m-value and the other percentages of SBS and Gilsonite have been used in this study have an influence on this parameter. It can be revealed from the results that except changing SBS percentage from 0% to 5% and vice versa the other percentages of SBS and Gilsonite have a significant effect on G*/sin δ.

Table 8. Mean Comparison of BBR Test Parameters and G*/sin δ for Modifiers Dosages by using the Tukey Test.

Variable	SBS modified binders				Gil modified binders			
	Variable levels	Mean Difference	Sig.	95% Confidence Interval	Variable levels	Mean Difference	Sig.	95% Confidence Interval

					Lower Bound	Upper Bound					Lower Bound	Upper Bound
Stiffness in BBR test	0	3	18.11	2.1E-04	9.2	27	0	8	-71.56	4.60E-06	-100	-42
		5	24.15	6.0E-05	13	35		12	-120.70	3.40E-10	-150	-91
	3	0	-18.11	2.1E-04	-27	-9.2	8	0	71.56	4.60E-06	42	100
		5	6.04	3.5E-01	-4.8	17		12	-49.14	7.40E-04	-79	-19
	5	0	-24.15	6.0E-05	-35	-13	12	0	120.70	3.40E-10	91	150
		3	-6.04	3.5E-01	-17	4.8		8	49.14	7.40E-04	19	79
m-value in BBR test	0	3	0.01	2.1E-02	1.7E-03	2.1E-02	0	8	0.03	4.80E-07	0.02	0.04
		5	0	9.8E-01	-1.3E-02	1.1E-02		12	0.04	1.40E-09	0.03	0.05
	3	0	-0.01	2.1E-02	-2.1E-02	-1.7E-03	8	0	-0.03	4.80E-07	-0.04	-0.02
		5	-0.01	4.2E-02	-2.4E-02	-4.0E-04		12	0.01	4.40E-02	0.00	0.02
	5	0	0	9.8E-01	-1.1E-02	1.3E-02	12	0	-0.04	1.40E-09	-0.05	-0.03
		3	0.01	4.2E-02	4.0E-04	2.4E-02		8	-0.01	4.40E-02	-0.02	0.00
G*/Sin (delta)	0	3	-1.74	1.2E-01	-3.90	0.43	0	8	-2.19	1.30E-01	-4.90	0.48
		5	-3.38	3.5E-03	-5.60	-1.20		12	-5.29	1.60E-04	-8.00	-2.60
	3	0	1.74	1.2E-01	-0.43	3.90	8	0	2.19	1.30E-01	-0.48	4.90
		5	-1.65	1.5E-01	-3.80	0.52		12	-3.10	2.00E-02	-5.80	-0.43
	5	0	5.29	0.0E+00	2.60	8.00	12	0	5.29	1.60E-04	2.60	8.00
		3	3.1	2.0E-02	0.43	5.80		8	3.10	2.00E-02	0.43	5.80

The results of Tukey test for test temperature in significance level as high as 0.95 shown in Table 9. As shown in this Table, the difference between the means of changing temperature from -24 °C to -18 °C, -12 °C, -6 °C and vice versa and from -18 °C to -12 °C, -6 °C and vice versa and from -12 °C to -6 °C and vice versa for both two binders modified with SBS and Modified with Gilsonite is significant. It seems that temperature changing in the range mentioned previously has an influence on stiffness and m-value for both types of modified samples. The results for G*/sin δ depict that there is no significance difference between the means of temperature changing from 64 °C to 70 °C and vice versa in significance level equal to .05 for SBS and Gilsonite modified binders. It means this range of temperature changing does not have an effect on G*/sin δ. On the other hand, the G*/sin δ is affected by temperature changes from 58 °C to 64 °C, 58 °C to 70 °C and vice versa.

Table 9. Mean Comparison of BBR Test Parameters and G*/sin δ for different Test Temperatures by using the Tukey Test.

Variable	Variable levels		SBS modified binders: Mean Difference	Sig.	95% Confidence Interval: Lower Bound	Upper Bound	Gil modified binders: Mean Difference	Sig.	95% Confidence Interval: Lower Bound	Upper Bound
in B	-24	-18	239.81	1.0E-12	230	250	247.91	8.0E-13	220	280

		-12	351.41	1.0E-12	340	360	388.39	8.0E-13	360	420
		-6	417.32	1.0E-12	400	430	481.29	8.0E-13	450	510
	-18	-24	-239.81	1.0E-12	-250	-230	-247.91	8.0E-13	-280	-220
		-12	111.59	1.0E-12	99	120	140.48	1.6E-11	110	170
		-6	177.51	1.0E-12	170	190	233.38	8.0E-13	200	260
	-12	-24	-351.41	1.0E-12	-360	-340	-388.39	8.0E-13	-420	-360.
		-18	-111.59	1.0E-12	-120	-99	-140.48	1.6E-11	-170	-110
		-6	65.91	1.7E-10	53	78	92.89	5.4E-08	63	120
	-6	-24	-417.32	1.0E-12	-430	-400	-481.29	8.0E-13	-510	-450
		-18	-177.51	1.0E-12	-190	-170	-233.38	8.0E-13	-260	-200
		-12	-65.91	1.7E-10	-78	-53	-92.89	5.4E-08	-120	-63
m-value in BBR test	-24	-18	-0.05	1.5E-08	-0.07	-0.04	-0.05	1.1E-11	-0.06	-0.04
		-12	-0.10	1.9E-12	-0.11	-0.09	-0.09	8.0E-13	-0.10	-0.08
		-6	-0.14	1.0E-12	-0.15	-0.12	-0.12	8.0E-13	-0.13	-0.11
	-18	-24	0.05	1.5E-08	0.04	0.07	0.05	1.1E-11	0.04	0.06
		-12	-0.05	1.9E-07	-0.06	-0.03	-0.04	1.6E-08	-0.05	-0.03
		-6	-0.08	2.5E-11	-0.10	-0.07	-0.07	8.1E-13	-0.08	-0.06
	-12	-24	0.10	1.9E-12	0.09	0.11	0.09	8.0E-13	0.08	0.10
		-18	0.05	1.9E-07	0.03	0.06	0.04	1.6E-08	0.03	0.05
		-6	-0.04	4.8E-06	-0.05	-0.02	-0.04	2.5E-08	-0.05	-0.02
	-6	-24	0.14	1.0E-12	0.12	0.15	0.12	8.0E-13	0.11	0.13
		-18	0.08	2.5E-11	0.07	0.10	0.07	8.1E-13	0.06	0.08
		-12	0.04	4.8E-06	0.02	0.05	0.04	2.5E-08	0.02	0.05
G*/Sin (delta)	58	64	2.62	1.9E-02	0.45	4.80	3.30	2.2E-03	1.20	5.40
		70	3.79	1.5E-03	1.60	6.00	4.62	6.5E-05	2.60	6.80
	64	58	-2.62	1.9E-02	-4.80	-0.45	-3.30	2.2E-03	-5.40	-1.20
		70	1.17	3.6E-01	-1.00	3.30	1.39	2.3E-01	-0.70	3.50
	70	58	-3.79	1.5E-03	-6.00	-1.60	-4.68	6.5E-05	-6.80	-2.60
		64	-1.17	3.6E-01	-3.30	1.00	-1.39	2.3E-01	-3.50	0.70

IV. Conclusion

Based on the analysis of test results, following findings were concluded:

- In terms of aging properties and temperature susceptibility, the results indicate that TS and RAI decrease with adding SBS and Gilsonite to the neat binders.
- The results of physical and rheological tests show that adding Gilsonite and SBS to binder can increase viscosity and G*/ Sin (δ). In addition, BBR test results show that both Gilsonite and SBS do not have a good effect on the low performance grade of binder and cause an increase in low temperature performance.The results of ANOVA reveal that modifiers' dosage has an effect on temperature susceptibility, HT and LT continuous grade and PG temperature span. Also, stiffness, m-value and G*/ Sin (δ) are affected by modifiers' dosage and test temperature.
- The results of Tukey test indicate that addition of 3% and 5% SBS and 8% and 12% of Gilsonite to neat binder have an influence on temperature susceptibility. The results also indicate that the difference between the means of all dosages of Gilsonite and SBS for HT continuous grade is significant. The results for the LT continuous grade show that except SBS dosages from 3% to 5% and vice versa, the difference between the means of other percentages of SBS and Gilsonite have been used in this study is significant.
- The results of the effect of SBS and Gilsonite dosages on stiffness in significance level as high as 0.95 reveals that stiffness is affected by all amounts of modifiers except adding 2% SBS to 3% SBS modified binders.

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