Hindawi
Advances in Civil Engineering
Volume 2019, Article ID 8521682, 7 pages
https://doi.org/10.1155/2019/8521682

Research Article

Evaluating Iraqi Modified Asphalt Concrete Moisture Resistance Based on Strength Ratio and Fracture Energy Parameters

Zahir Noori M. Taki, Alaa H. Abed, and Hasan Al-Mosawe

Civil Engineering Department, Al-Nahrain University, Baghdad, Iraq

Correspondence should be addressed to Hasan Al-Mosawe; hasan.al-mosawe@eng.nahrainuniv.edu.iq

Received 8 March 2019; Revised 20 May 2019; Accepted 1 June 2019; Published 26 June 2019

Academic Editor: Belén González-Fonteboa

Two types of polymers (plastomer (functionalized polyethylene (PE)) and elastomer (styrene-butadiene-styrene (SBS))) were used for shifting up asphalt binder performance grade (PG) and tensile strength resistance (moisture damage) of the asphalt concrete mixture. It is found that adding 3.5% functionalized polyethylene (PE) polymer to the binder is more effective than adding 4% styrene-butadiene-styrene (SBS) to shift up asphalt PG by two grades to PG 76-16. Furthermore, the viscosity of the binder increased about 200% when using 4% SBS, while there is no significant effect on viscosity when 3.5% PE is used. Therefore, there is no need to increase the temperature of mixing and compaction which may affect polymers. The indirect tensile test was used for measuring tensile strength ratio of dry and wet samples (conditioned according to ASTM D4867) and found that this ratio increased by 10 to 18% when using 4% SBS and 3.5% PE, respectively. Fracture energy (area under the strength-strain curve) and elasticity were estimated for neat and modified mixture samples.

1. Introduction

Due to the increase in traffic volume and temperature, better performance of the asphalt pavement is required; therefore, less susceptible asphalt mixture to a high temperature to resist rutting, temperature cracking, and moisture damage should be produced. Asphalt properties can be improved by polymers in order to get the best performance of road pavements. Modification of asphalt is mainly dependent upon the polymer concentration, the chemical composition, the molecular weight, the raw source, the reference of asphalt grade, and the process of refining [1]. Polymers are usually mixed with asphalt to increase the stiffness and elasticity and decrease stripping or moisture sensitivity of the HMA, and sometimes for aging resistance. When polymers are used as a modifier to the asphalt binder, some properties should be considered, such as the compatibility with the binder, the feasibility of mixing and laying with the conventional methods and tools in the field, and the workability of the mixture during the mixing process [2]. In general, there are two types of polymers: elastomers such as styrene-butadiene-styrene (SBS) and plastomers such as functionalized polyethylene. The SBS elastomer modifier is mostly utilized as an asphalt binder modifier in the bitumen industries [3]. The addition of SBS to the asphalt binder would result in an improvement in the permanent deformation resistance of the asphalt binder (which is expressed by $G^*/\sin\delta$) due to the absorption of bitumen oil portion by the elastomer phase of the modifier [4, 5]. Asphalt mixtures suffer from different types of distresses. One of the major distresses is moisture damage, which is defined as the reduction in the mixture strength due to the effective existence of the moisture in voids. The moisture damage appears in two mechanisms when the load is applied: stripping (adhesion loss) and softening (cohesion loss) [6, 7].

2. Aims and Objectives

The aim of this paper is to improve the rheological properties of the Iraqi asphalt binder by modifying it with two types of polymers, plastomer and elastomer (SBS and PE), and increasing moisture resistance of modified local asphalt mixtures which will be proved by using the indirect tensile test and fracture energy theory.

3. Materials and Methods

The rheological characteristics are achieved by conducting Superpave tests such as dynamic shear rheometer (DSR) and bending beam rheometer (BBR) tests, rolling thin film oven (RTFO), and pressure aging vessel (PAV). RTFO and PAV are used to simulate the short- and long-term aging of asphalt, respectively. The rotational viscosity (RV) test has been used to characterize the mixing and compaction temperatures. The rheological characteristics of the control bitumen are tabulated in Table 1, and it has been found that the PG is (64-16).

3.1. Polymers. In the last few decades, polymers are widely used as asphalt modifiers to improve the asphalt concrete performance in the field to withstand the growth of traffic volume. The addition of polymers to the binder will eventually increase the resistance of the asphalt concrete mixture to rutting, moisture damage, and fatigue cracking.

The bitumen rheological properties are affected by polymer chain arrangement. Each chain in the polymer has several monomers that contribute to identifying the degree of polymerization. The properties of the polymer are dependent upon the length of its chain and the range of the cross-links and the production methods [8]. Daurah asphalt binder is utilized in this study as the neat bitumen, and two types of polymers according to deformation properties are used, which are "styrene-butadiene-styrene" (SBS) elastomer and "functionalized polyethylene" (PE) plastomer.

3.2. Polymer Concentration. The production (mixing) temperature is considered an important factor that should be controlled. The increase in the content of the modifier would result in an increase in the modified binder viscosity which eventually would require higher mixing temperatures [9]. Based on the previous research by Abed [10], which studied different percentages of SBS and functionalized PE, it has been found that 4% SBS and 3.5% PE increased the PG by two grades (PG 76-16) which is required in Iraq. Therefore, 4% SBS and 3.5% PE were considered in this research to increase the performance of the asphalt binder by two grades compared to the neat binder.

3.3. Preparation of Polymer-Asphalt Concrete Mixtures. The preparation of the modified asphalt bitumen requires mixing the neat binder with the modifier. Two methods of mixing are known in this matter which are performed by the high and the low shear mixer. The low shear mixer simply consists of a blending container and a stirrer. The blending process would result in mixing the neat binder with the modifier by either swelling or dissolving process, and the temperature should be constant during mixing.

The high shear mixer is used to reduce the size of polymer particles by mixing using mechanical shear and hydrodynamic efforts. In this case, the temperature is increased during the mixing process at a constant rate to allow the polymer to be dissolved in the neat binder and to produce a homogeneous mixture [11]. After considering the RTFO and PAV tests, it was ensured that the polymer did not separate or deposit from the binder which gives an indication of compatibility and stability.

The process started with heating up the neat binder to 160°C for 60 minutes, and then the SBS was added gradually to the neat binder and mixed mechanically for 30 minutes using a locally manufactured mixer simulated for this purpose. After the polymer addition process was completed, the mixture was then stirred in the mixer for 120 minutes at 180°C and at a shear rate of 2220°rpm to produce a homogeneous mixture; the mixing process is shown in Figure 1.

The mixing process is terminated when the resulting modified asphalt is kept stable and does not climb the mixer shaft which gives an indication of homogeneity. However, if particles of the modifier are still visible in the mixture, the mixing process should be continued until the modifier is fully dissolved in the binder.

On the contrary, mixing the PE modifier with the neat binder is easier than mixing the SBS modifier due to the lower temperature and duration required for mixing, 145°C and 90 minutes, respectively. This will reduce the effect of oxidation during mixing.

3.4. Modification of Asphalt Binder. The rheological characteristics that are listed in Table 1 for the base asphalt binder do not meet traffic, climate, and pavement structure requirements in Iraq. Therefore, it is required to raise the performance grade of the local asphalt binder by incorporating modifier as one of the good processes to enhance the asphalt binder characteristics, which is related to pavement failure.

It is noticed that the effect of different polymers on the failure modes is associated with the type of interlinkage between the asphalt binder and polymer, the molecular nature of the polymer additive, and the way of dispersion in the asphalt [12]. Tables 2 and 3 show Superpave parameters of the modified asphalt binder with 4% and 3.5% SBS and PE, respectively.

3.5. Selection of Aggregate Gradation. The aggregate mixture with 12.5 mm nominal maximum size is selected. The gradation of the aggregate meets the range of gradation limits specified by SCRB [13] for dense mixtures of the wearing course, as shown in Figure 2. The aggregate particles were sieved and separated to various sizes and stored in bins to be batched in preparing the asphalt mixture.

Two samples were prepared for each binder content for the evaluation of the optimum binder content. Samples are then compacted using the gyratory compactor. The ESAL for Baghdad City was 30 million to determine the number of gyrations that should be performed in the gyratory compactor. Table 4 shows the initial, design, and maximum number of gyrations (N_{initial}, N_{design}, and $N_{\max}$)

Table 1: Rheological characteristics of the Daurah bitumen.

Type of asphalt		Daurah PG 64-16		
Parameter	Standard specification	Temperature measured	Parameter measured	Requirements
Aging		*Original binder*		
Rotational viscosity (Pa·s)	ASTM D 4402	135°C	0.544	3 (max.)
Dynamic shear rheometer (DSR) $G^*/\sin\delta$ (kPa)	ASTM D 7175	64°C 70°C	2.15 0.923	1 (min.)
Ductility (5 cm/min)	ASTM D 113	25°C	>100	>100
Aging		*Rolling thin film oven (RTFO) residue*		
Dynamic shear rheometer (DSR) $G^*/\sin\delta$ (kPa)	ASTM D 7175 ASTM D 2872	70°C	1.91	2.2 (min.)
Mass loss (%)	ASTM D 2872		0.55	1 (max.)
Aging		*Pressure aging vessel (PAV-110 C) residue*		
Dynamic shear rheometer (DSR) $G^*/\sin\delta$ (kPa)	ASTM D 7275 ASTM D 6521	34°C	3300	5000 (max.)
Bending beam rheometer (BBR) creep stiffness (MPa)	ASTM D 05	−16°C	185	300 (max.)
Bending beam rheometer (BBR)	ASTM D 6648	−16°C	0.41	0.3 (min.)

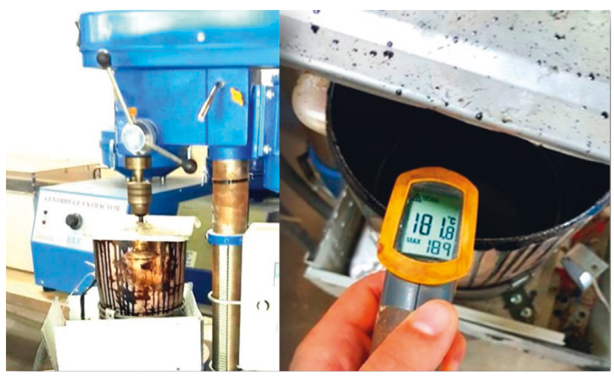

Figure 1: Mixing process of asphalt with SBS.

Table 2: Superpave parameters of the Daurah modified binder with 4% SBS.

Type of asphalt		Daurah PG 76-16 with 4% SBS		
Parameter	Standard specification	Temperature measured	Parameter measured	Requirements
Aging		*Original binder*		
Rotational viscosity (Pa·s)	ASTM D 4402	135°C	1.45	3 (max.)
Dynamic shear rheometer (DSR) $G^*/\sin\delta$ (kPa)	ASTM D 7175	70°C 76°C	6.39 2.01	1 (min.)
Ductility (5 cm/min)	ASTM D 113	25°C	>200	>100
Aging		*Rolling thin film oven (RTFO) residue*		
Dynamic shear rheometer (DSR) $G^*/\sin\delta$ (kPa)	ASTM D 7175 ASTM D 2872	76°C	3.25	2.2 (min.)
Mass loss (%)	ASTM D 2872		0.51	1 (max.)
Aging		*Pressure aging vessel (PAV-110 C) residue*		
Dynamic shear rheometer (DSR) $G^*/\sin\delta$ (kPa)	ASTM D 7275 ASTM D 6521	34°C	2100	5000 (max.)
Bending beam rheometer (BBR) creep stiffness (MPa)	ASTM D 05	−16°C	223	300 (max.)
Bending beam rheometer (BBR)	ASTM D 6648	−16°C	0.34	0.3 (min.)

specified for the ESALs according to the study in [14]. It is important to mention that all the samples are compacted using $N_{\max}$ to find the optimum asphalt content, while the compaction and volumetric properties are estimated at the design number of gyrations for all trials of bitumen content. The calculation of $\%G_{mm}$ with the required

Table 3: Superpave parameters of the Daurah modified binder with 3.5% PE.

Type of asphalt			Daurah PG 76-16 with 3.5% PE	
Parameter	Standard specification	Temperature measured	Parameter measured	Requirements
Aging			*Original binder*	
Rotational viscosity (Pa·s)	ASTM D 4402	135°C	0.576	3 (max.)
Dynamic shear rheometer (DSR) $G^*/\sin\delta$ (kPa)	ASTM D 7175	70°C 76°C	2.41 1.821	1 (min.)
Ductility (5 cm/min)	ASTM D 113	25°C	>100	>100
Aging			*Rolling thin film oven (RTFO) residue*	
Dynamic shear rheometer (DSR) $G^*/\sin\delta$ (kPa)	ASTM D 7175 ASTM D 2872	76°C	2.45	2.2 (min.)
Mass loss (%)	ASTM D 2872		0.62	1 (max.)
Aging			*Pressure aging vessel (PAV-110 C) residue*	
Dynamic shear rheometer (DSR) $G^*/\sin\delta$ (kPa)	ASTM D 7175 ASTM D 6521	34°C	2800	5000 (max.)
Bending beam rheometer (BBR) creep stiffness (MPa)	ASTM D 05	−16°C	178	300 (max.)
Bending beam rheometer (BBR)	ASTM D 6648	−16°C	0.41	0.3 (min.)

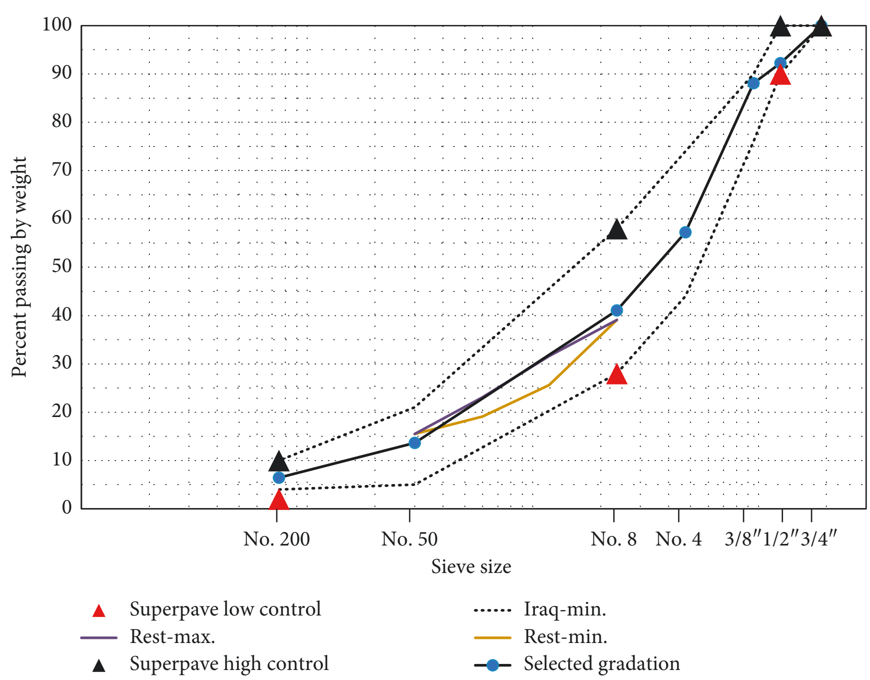

Figure 2: Aggregate gradation.

Table 4: Superpave gyratory compaction effort according to AASHTO-R35.

Design ESALs (million)	Compaction parameters $N_{initial}$	N_{design}	N_{max}
<0.3	6	50	75
0.3 to <30	7	75	115
3 to <30	8	100	160
≥30	9	125	205

Table 5: Superpave gyratory compaction relation with $\%G_{mm}$ for finding the optimum asphalt content.

No. of gyrations	$\%G_{mm}$ 4.6	5.2	5.8	Optimum content (%) 4.80
8	87.0	88.0	89.0	87.3
100	95.5	97.0	98.0	96.0
160	97.0	98.0	99.0	97.3

gyrations ($N_{initial}$ was achieved less than 89%, N_{design} equaled 96%, and N_{max} was achieved less than 98%) is tabulated in Table 5.

Viscosity of the binder plays an important role in the estimation of the compaction and mixing temperature, especially when the asphalt was modified with polymers [15]. The change in density with respect to the number of gyrations can be calculated by making use of the specimen height change and the bulk specific gravity of the sample. Figure 2 shows aggregate gradation.

4. Results and Analysis

A modifier can be selected to enhance one or more of the main performance-related properties of asphalt. Tables 1–3 show Superpave parameters estimated according to Superpave standard tests under various temperatures for raw and two types of modified binders. It can be seen that although the PE modifier is shifting up the performance grade with the same jump of the SBS modifier, there are no significant effects on viscosity. Therefore, there is no need to increase the temperature of mixing and compaction which may affect polymers, and consequently, aging is not affected. However, regarding SBS, three steps were performed to decrease the effect of aging which are increasing the mixing energy by using larger stirring arms, increasing temperature to 180°C, and using a cover to prevent oxidation during mixing. These steps resulted in a decrease in mixing time which eventually slowed down the aging process. Furthermore, 3.5% PE is used for shifting up the performance by two grades, while 4% SBS is needed to achieve PG 76-16. Since the goal of this study is to evaluate the moisture resistance of the mixture due to the addition of polymers, the mixture fatigue resistance was not studied intensively. However, the modified binder resistance to fatigue was characterized and represented as $G^*/\sin\delta$ and is shown in Tables 1–3 and found to be improved.

Dry and wet conditions were used to evaluate the maximum indirect tensile strength of the samples. Figures 3 and 4 show a comparison of tensile strength-strain curve results for the neat and modified mixtures and depict the effect of the modified binder type for wet (conditioned) and dry (unconditioned) samples. The results indicated that the moisture negatively affected the indirect tensile strength results. The conditioned samples according to ASTM D4867 suffered from less strength compared to unconditioned samples, as shown in Figure 5.

On the contrary, the mixture that is modified with functionalized polyethylene has higher strength for both dry and wet samples. Figures 6 and 7 show the effects of modifier type on fracture energy (area under the strength-strain curve) and elasticity (maximum slope of the strength-strain curve). The results in Figure 8 depict that the mixture modified with functionalized polyethylene has higher maximum tensile strength ratio and fracture energy ratio than the mixture modified with styrene-butadiene-styrene. It can be concluded that the TSR and fracture energy are higher for functionalized polyethylene than SBS. This is due to the fact that the functionalized polyethylene is a plastomer polymer which has small effect on the viscosity of the modified binder unlike SBS which absorbs oil fractions of the binder and causes swelling of the elastomers which will result in high viscosity of the modified binder due to the physical network between the modifier and the binder. Consequently, the adhesion of the aggregate with the modified binder will be improved.

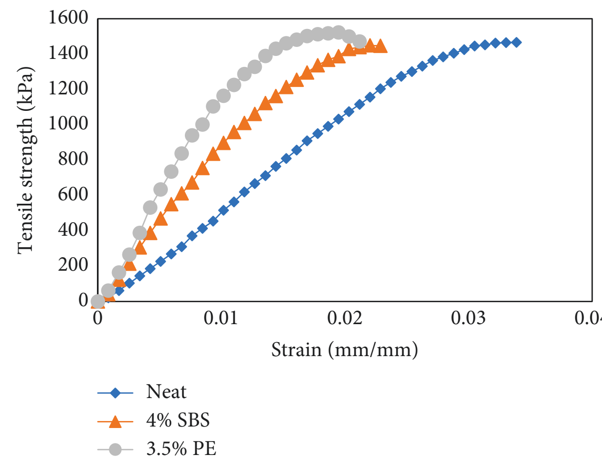

Figure 3: Effects of the modified binder on the strength-strain curve for unconditioned (dry) samples.

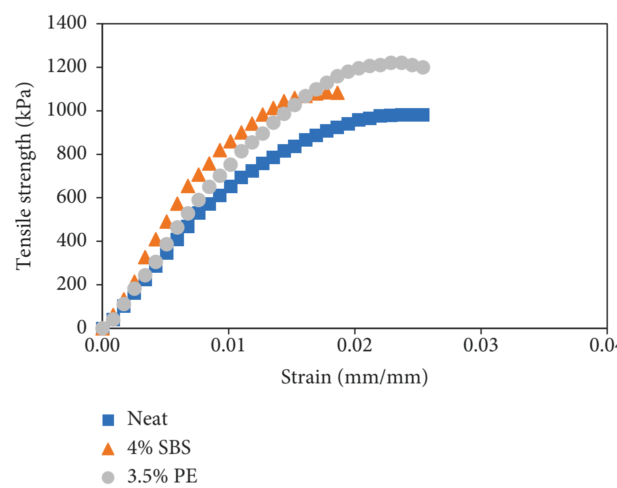

Figure 4: Effects of the modified binder on the strength-strain curve for conditioned samples.

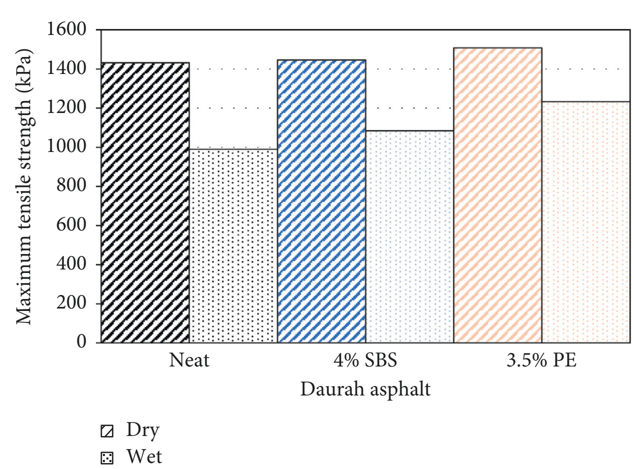

Figure 5: Maximum tensile strength vs. types of polymers.

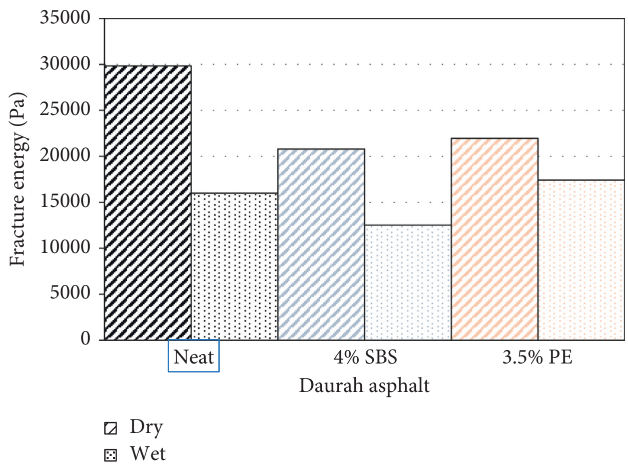

Figure 6: Fracture energy vs. types of polymers.

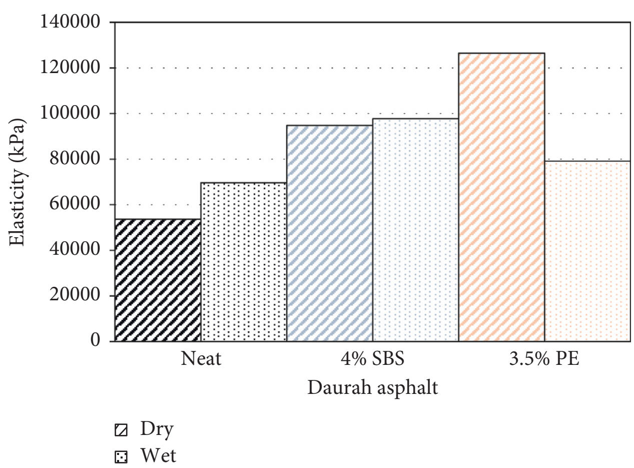

Figure 7: Elasticity vs. types of polymers.

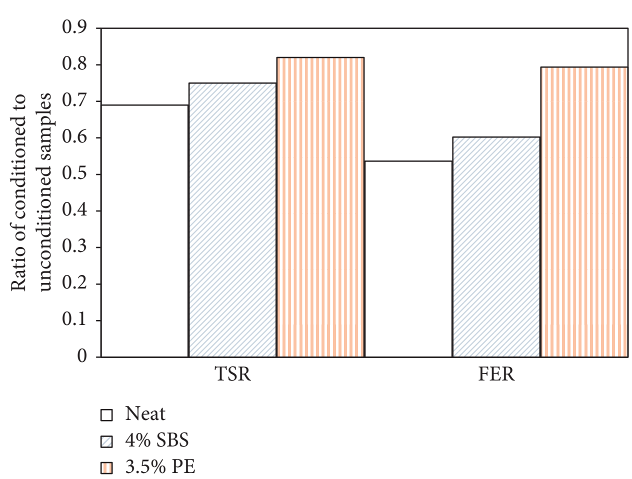

Figure 8: Effects of modified asphalt on the TSR and FER.

5. Conclusions

Two types of polymers were added to the Iraqi asphalt binder in this research: "functionalized polyethylene" (3.5% PE) plastomer and "styrene-butadiene-styrene" (4% SBS) elastomer. According to Superpave technology, the rheological properties were found for base asphalt to be PG 64-16; for modified asphalt, the PG was raised to PG 76-16 for both types of modifiers. The viscosity of binders increased to about 200% when 4% SBS was used, while there was no significant effect on viscosity when 3.5% PE was used. Therefore, there is no need to increase the temperature of mixing and compaction which may affect polymers. The results of wet samples showed that the elasticity was increased by 40% and 14% by adding 4% SBS and 3.5% PE, respectively. Nevertheless, the area of fracture decreased by 22% as 4% SBS was used and increased by 14% for 3.5% PE. Regarding percent of strength ratio, it was increased by 18% and 10% when modified by 3.5% PE and 4% SBS, respectively.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] Y. Yildirim, "Polymer modified asphalt binders," *Construction and Building Materials*, vol. 21, no. 1, pp. 66–72, 2007.

[2] X. Lu and U. Isacsson, "Effect of binder rheology on the low-temperature cracking of asphalt mixtures," *Road Materials and Pavement Design*, vol. 2, no. 1, pp. 29–48, 2001.

[3] A. H. Abed and A. M. Oudah, "Rheological properties of modified asphalt binder with nanosilica and SBS," *IOP Conference Series: Materials Science and Engineering*, vol. 433, no. 1, article 012031, 2018.

[4] A. H. Abed and A. H. Nasser, "Assessment mixing and compaction temperatures for modified HMA using Superpave high shear viscosity methods," *Al-Nahrain Journal for Engineering Sciences*, vol. 21, no. 4, pp. 516–522, 2018.

[5] B. Sengoz and G. Isikyakar, "Evaluation of the properties and microstructure of SBS and Eva polymer modified bitumen," *Construction and Building Materials*, vol. 22, no. 9, pp. 1897–1905, 2008.

[6] R. Moraes, R. Velasquez, and H. U. Bahia, "Measuring the effect of moisture on asphalt-aggregate bond with the bitumen bond strength test," *Transportation Research Record: Journal of the Transportation Research Board*, vol. 2209, no. 1, pp. 70–81, 2011.

[7] P. E. Sebaaly, D. Little, E. Y. Hajj, and A. Bhasin, "Impact of lime and liquid antistrip agents on properties of Idaho hot-mix asphalt mixture," *Transportation Research Record: Journal of the Transportation Research Board*, vol. 1998, no. 1, pp. 65–74, 2007.

[8] K. Kanitpong and H. Bahia, "Relating adhesion and cohesion of asphalts to the effect of moisture on laboratory performance of asphalt mixtures," *Transportation Research Record: Journal of the Transportation Research Board*, vol. 1901, no. 1, pp. 33–43, 2005.

[9] H. H. Joni and E. K. Shaker, "Determination of the acceptable range of mixing and compaction temperatures for modified asphalt mixture with styrene butadine styrene (SBS)," *International Journal of Current Engineering and Technology*, vol. 7, no. 5, 2017.

[10] A. H. Abed, "Effects of functionalized polyethylene and styrene butadiene styrene polymers on performance grade of local asphalt binder," *Journal of Engineering*, vol. 18, no. 6, pp. 735–742, 2012.

[11] S. Bitumen, *The Shell Bitumen Industrial Handbook*, Thomas Telford, London, UK, 1995.

[12] H. U. Bahia, H. Zhai, K. Bonnetti, and S. Kose, "Non-linear viscoelastic and fatigue properties of asphalt binders," *Journal of the Association of Asphalt Paving Technologists*, vol. 68, pp. 1–34, 1999.

[13] SCRB, R/9, *General Specification for Roads and Bridges (SERB/R9)—Hot Mix Asphaltic Concrete Pavement*, Department of Planning and Studies, Republic of Iraq, Ministry of Housing and Construction, Baghdad, Iraq, 2003.

[14] AASHTO R-35, *Standard Specifications for Transportation Materials and Methods of Sampling and testing, Superpave Volumetric Design for Asphalt Mixtures*, AASHTO Publications, Washington, DC, USA, 2015.

[15] F. L. Roberts, P. S. Kandhal, E. R. Brown, D. Y. Lee, and T. W. Kennedy, *Hot Mix Asphalt Materials, Mixture Design, and Construction*, Napa Education Foundation, Lanham, Maryland, 1996.