Effect of Styrene-Butadiene-Styrene on the Properties and Grading of Local Asphalt Binder in the UAE

Ali Alnaqbi 1,*, Waleed Zeiada 1,2 Ghazi Al-Khateeb 1,3, Helal Ezzat 1, Abdallah Shanableh 1

1.Department of Civil and Environmental Engineering, College of Engineering, University of Sharjah, Sharjah, 27272 Sharjah, UAE.
2.Department of Public Works Engineering, College of Engineering, Mansoura University, Egypt.
3.Jordan University of Science and Technology, Irbid, Jordan

*Corresponding author: U18200514@sharjah.ac.ae

Abstract. Flexible pavements in the UAE are subjected to heavy traffic loading repetitions and severe weather conditions which are the main causes of local pavement deteriorate. Fatigue cracking and rutting are most common deterioration types. One effective solution to mitigate both pavement distresses is to use asphalt modifier technologies to improve the properties of asphalt binders used locally in the UAE. The main goal of this study is investigating the effects of Styrene-Butadiene-Styrene (SBS) on the rheological properties of local asphalt binder as well as its grade based on both penetration and Superpave grading systems. Three different SBS contents of 2.5%, 4.5%, and 6.5% by weight of asphalt binder were utilized. It was found that increasing SBS content increased the asphalt binder softening point and rotational viscosity and decreased the penetration value. SBS-modified asphalt binders were less susceptible to temperature changes. Superpave performance results showed that SBS-modified asphalt binders exhibited higher rutting parameter G*/Sin δ values as the SBS content increased for both unaged and short-term-aged conditions. Adding 2.5% SBS increased the asphalt penetration grade from 60/70 to 40/50 and the performance grade (PG) from 64 to 70. For the 4.5% and 6.5% SBS cases, the asphalt binder PG increased to 76 and 88 respectively. SBS-modified asphalt binders were found to possess significantly higher mixing and compaction temperature ranges compared to the control asphalt binder.

1. Introduction

The traffic volumes in the United Arab Emirates (UAE) had tremendously risen in the last decade due to the fast-pace development of the country. This increase in traffic volumes combined with the harsh environment of the UAE accelerates the deterioration of asphalt pavements especially in areas of congested and heavy traffic [1]. In order to accommodate heavy traffic loadings as well as resist extreme high temperatures, specific polymer-based additives were utilized. Polymer modified asphalt binders have been used successfully at locations of higher loading stresses, such as intersections, airports, vehicle weigh stations, and race tracks [2-6].

There are various types of polymers used to modify and improve the properties of asphalt binders [7-10]. Polymer-modified asphalt binders tend to increase the stiffness at higher temperatures while maintain flexibility at lower temperatures [11]. The most commonly used polymer is elastomeric type styrene-butadiene–styrene (SBS) copolymer. The most common form used in asphalt binder
modification is a linear SBS structure [12]. A tremendous number of studies have shown that SBS-modified asphalt binders increased the resistance of asphalt mixtures against rutting [13, 14-17], fatigue cracking [18-20], low-temperature cracking [21-23] and moisture damage [24-25]. When SBS polymer is mixed with asphalt, the polybutadiene phase absorbs the asphalt binder maltene fraction and swells up to nine times its initial volume. At a suitable SBS concentration, normally between 3 and 5%, a polymer network is homogenously formed throughout the asphalt binder matrix and this changes substantially the asphalt binder properties [26-28].

Many researchers have studied the effects of SBS polymers on the asphalt binder properties and they found that the addition of SBS tended to decrease the penetration and increase the softening point of the binder [29-34]. It was found that there is a significant decrease in the penetration values and a considerable increase in the softening point temperatures of SBS-modified asphalt binders at polymer content range of 3% to 5% [35]. For Superpave test, many researchers concluded that increasing SBS content increased the complex shear modulus (G*) and decreased the phase angle (δ). Also, as SBS content increased, rutting parameter (G*/ Sinδ) increased as well, meaning more rutting resistance [31-34, 36, 37].

2. Research Objectives
The main objective of this study is to investigate the effect of using different percentages of SBS polymer on the rheological properties and grading of 60/70 local asphalt binder.

3. Materials and Testing Plan
All the asphalt binders used in this study were prepared locally in the UAE by MENA Energy Company. The control asphalt binder used in this study is graded as 60/70 according to the penetration grading system. Table 1 presents the basic properties of the 60/70 asphalt binder used locally in most of roadway projects.

| Parameter                  | Value   | Standard                  |
|----------------------------|---------|---------------------------|
| Performance Grade          | PG 64–10| ASTM D 7175 Error!       |
| Penetration grade          | 60/70   | ASTM D5 Error!           |
| Softening point (Ring and Ball) | 47.3°C | ASTM D36 Error!          |
| Rotational viscosity at 135°C | 1613 cP| ASTM D4402 Error!        |

A total of 4 asphalt binders were tested including the control and SBS-modified asphalt binders using SBS contents of 2.5, 4.5 and 6.5% by weight of asphalt binder. The asphalt binders were tested without aging for penetration system grading. Figure 1 shows the detailed testing plan of this study.
4. Testing Methods

4.1 Penetration Test
According to ASTM D5 [39], the penetration test was carried out to measure the influence of SBS-modification on asphalt binder hardening. First, a set of two standard cans were filled with preheated asphalt binders and were kept at room temperature to cool down for two hours. Afterwards, the samples were immersed in a water bath set at 25 °C degrees for additional two hours. The average of three needle penetrations with 100g applied weight for 5 seconds were then recorded. Two replicate were performed for each asphalt binder.

4.2 Softening Point Test
The softening point (ring-and-ball) test was performed based on the ASTM D36 [40] standard to evaluate the softening point of asphalt binder before and after modification. A set of two rings were filled with heated soft asphalt binder then trimmed after cooling for 30 minutes placed on loading frame then immersed into a water bath at a temperature of 5±1 °C. The samples were then heated up in a standard gradual rate under the load of standard steel balls till the asphalt binder samples travels a distance of 25 mm. The measured temperature at this point is set to be the softening point. Two replicate were performed for each asphalt binder.

4.3 Rotational-Viscometer (RV) Test and Temperature susceptibility
The rotational viscometer determines the asphalt binder viscosity by measuring the torque necessary to maintain a constant rotational speed of a cylindrical spindle submerged in an asphalt binder specimen held at a constant temperature, as per the ASTM D4402 / D4402M-15 [41]. The Brookfield rotational viscosity values are measured at three temperatures of 135, 150 and 165°C. Standard steel tube is filled with 10 gm of asphalt binder then inserted into the device’s chamber which is capable of maintaining a set temperature. The average of three viscosity readings within three minutes was recorded for each temperature after 35 minutes of conditioning [41]. Two replicate were performed for each asphalt binder.
4.4 High Temperature Performance Grading

For the performance grading (PG) system, 25-mm samples were prepared in silicon molds then tested in the parallel plate system of the DSR at max pavement temperatures (64, 70, 76 ... etc.) till the bidder reached the 1 kPa limit under a strain level of 0.1 and frequency of 10 Hz. A conditioning of 25 minutes was applied before recording the complex modulus (G*) and the phase angle (δ) at a desired temperature [38]. The samples were then short-term aged using rolling thin film oven (RTFO) by placing 8 bottles that have 35 gm of asphalt binder in each inside a disk rotating in the vertical direction at a temperature of 163 °C for 85 minutes subjected to a standard air flow. The RTFO-aged samples were then tested using the DSR 25mm plate as mentioned previously but with a rutting limit of 2.2 kPa [38].

5. Results and Discussion

5.1 Penetration Test

The penetration test results are plotted in Figure 2 (a) that illustrates the average penetration value of the two replicate against the SBS content and it is observed that the penetration values decrease as the percentage of SBS increases. Similar results were reported elsewhere in previous studies [29–Error! Reference source not found.].

5.2. Softening Point Test

The softening point results are plotted in Figure 2 (b). The average softening point temperatures of the two replicate is shown against the SBS content. It is noticed that the softening point temperature of the SBS-modified asphalt binders is higher when compared to that of the control asphalt binder. Furthermore, it is observed that the softening point temperature increases as the SBS content increases. The increase in softening point is an indicator of the stiffening effect of SBS-modified asphalt binder, which is favourable since asphalt binders with higher softening point may be less susceptible to permanent deformation or rutting [29-34].

5.3. Rotational-Viscometer (RV) Test and Temperature susceptibility

It is generally observed from the RV test results that the viscosity values of all tested asphalt binders were consistently reduced as the test temperatures increases, as shown in Figure 3. It is widely known that the addition of SBS stiffens the asphalt binders [30-32, 34].

Figure 2. (a) Penetration; and (b) softening point test results
5.4. High Temperature Performance Grading

Figure 4 presents the DSR test results of the tested asphalt binders at various temperatures. The testing started typically at 64 °C and then the temperature was increased until the failure condition was attained achieve the minimum requirements of \((G*/\sin \delta = 1 \text{ kPa})\). SBS-modifier is found to significantly improve the performance of asphalt binders indicated by increased \(G^*\) and \(\delta\) values. These trends of \(G^*\) and \(\delta\) are known to be favored for the rutting resistance of asphalt binders and asphalt mixtures. The rutting parameter \((G*/\sin \delta)\) of all SBS-modified asphalt binder is higher than this of control asphalt binder at all test temperatures. The rutting resistance of the binder increases with an increase in the percentage of SBS content. Also, by the addition of 2.5, 4.5 and 6.5% SBS to the control asphalt, the rutting resistance is increased by more 2.0, 5.5 and 7.5 times at 64°C, respectively. This indicates an increased elastic behavior with higher SBS content.

\[
y(135^\circ C) = 376.57e^{0.3309x}, \quad R^2 = 0.9938
\]
\[
y(150^\circ C) = 193.32e^{0.3153x}, \quad R^2 = 0.9919
\]
\[
y(165^\circ C) = 108.25e^{0.3119x}, \quad R^2 = 0.9912
\]
The results of the DSR tests on RTFO-aged asphalt binders at high temperatures are presented in Figure 5. Figure 5 shows that the SBS-modification successfully improved the rheological properties of the asphalt binders against rutting resistance by increasing $G^*$ and decreasing $\delta$. The findings from the DSR test results using RTFO aging condition confirm those obtained from the unaged DSR tests results. The SBS successfully increased the values of PG rutting parameter ($G^*/\sin \delta$), which is an indication of being more rutting resistant. It is also worth noting that increasing the SBS content is found to increase the rutting parameter. The addition of 2.5, 4.5 and 6.5% SBS to the control asphalt binder increases the rutting resistance by more than 2, 2.8 and 4.3 times at 64°C, respectively. SBS-modified asphalt binders can resist the adverse effects of aging and deformation to a higher extent than the control asphalt binders. This observation confirms the findings from previous studies [31-34, 36-37].

![Figure 5. DSR rutting parameter ($G^*/\sin \delta$) test results for the RTFO residues](image)

The effects of temperature on the rutting factor of control and SBS-modified asphalt binders could be represented by the exponential function, expressed as follows:

$$\frac{G^*}{\sin \delta} = \alpha e^{\beta T}$$

Where $G^*/\sin \delta$ is the rutting factor, kPa; $\alpha$ is the properties of asphalt binder; $\beta$ is the influence coefficient of temperature; $T$ is the test temperature, °C.

According to the test results of control and SBS-modified asphalt binders at different temperatures, we can obtain the model parameters of the regression models as shown in Table 2.

### Table 2. Summary of regression parameters of control and SBS-modified asphalt binders.

| Asphalt Binders | Regression parameters | $R^2$ |
|-----------------|-----------------------|-------|
|                 | $\alpha$ | $\beta$ |       |
| **Un-aged Samples** |            |       |       |
| Control         | 5892.7   | -0.13  | 0.9998 |
| 2.5% SBS        | 1667     | -0.099 | 0.9974 |
| 4.5% SBS        | 1178.6   | -0.078 | 0.9965 |
| 6.5% SBS        | 973.4    | -0.071 | 0.998  |
| **RTFO-aged Samples** |            |       |       |
| Control         | 25079    | -0.139 | 0.9997 |
| 2.5% SBS        | 11217    | -0.116 | 0.9988 |
| 4.5% SBS        | 1995.1   | -0.083 | 0.9984 |
| 6.5% SBS        | 1849.4   | -0.076 | 0.9989 |
5.5. High Temperature Performance Grading

Penetration grading classifies different asphalt binders to 5 grades according to ASTM D946 [42] and to 12 grades according to European standards BS EN12591 [43] based on the results of the penetration test at 25 °C. The asphalt binder then has to comply with the limits of other tests or parameters. Table 3 presents the control and the SBS-modified asphalt binders grades as well as the standards limits for both ASTM and BS-EN.

### Table 3. Summary of asphalt binders penetration grading based on ASTM and BS Standards

| Asphalt Binder | Control       | 2.5% SBS | 4.5% SBS | 6.5% SBS |
|----------------|---------------|----------|----------|----------|
| ASTM Grade     | 60/70         | 40/50    | --       | --       |
| BS Grade       | 50/70         | 40/60    | 35/50    | 30/45    |
| Penetration at 25 °C (mm) | 62.10         | 46.33    | 38.83    | 33.50    |
| ASTM Limits    | 60 - 70       | 40 - 50  | --       | --       |
| BS Limits      | 50 - 70       | 40 - 60  | 35 - 50  | 30 - 45  |
| Softening point (°C) | 48.7          | 55.6     | 76.1     | 91.5     |
| ASTM Limits    | > 46          | > 49     | --       | --       |
| BS Limits      | 46 - 54       | 48 - 56  | 50 - 58  | 52 - 60  |
| Viscosity at 135 °C (mm²/s) | 382           | 803      | 1836     | 3112     |
| ASTM Limits    | --            | --       | --       | --       |
| BS Limits      | > 295         | > 325    | > 370    | > 400    |
| Penetration Index (PI) [38] | -0.975        | -0.087   | 3.180    | 4.524    |
| ASTM Limits    | --            | --       | --       | --       |
| BS Limits      | -1.5 - +0.7   | -1.5 - +0.7 | -1.5 - +0.7 | -1.5 - +0.7 |

It can be seen in Table 3 that control and 2.5% SBS-modified asphalt binders achieved the ASTM requirements for 60/70 and 40/50 and the BS standards requirements for 50/70 and 40/60 respectively. There is no grading for the 4.5% SBS and 6.5% SBS according to ASTM. Both of them achieved the requirements for viscosity at 135 °C and PI but failed to comply with the softening point upper limits.

5.6. Performance grading system

Superpave grading system classifies asphalt binders to 7 high temperature grades according to AASHTO M320 with several low temperature grades for each making them a total of 37 performance grades. The high temperature grading is based on the DSR (G*/Sin δ) for both original and RTFO residue. While the low temperature grades are based on the bending beam rheometer (BBR) stiffness (S) and m-value. Table 4 presents the grading of the control and SBS-modified asphalt binders based on AASHTO M320 [44].

According to Table 4, the performance grade (PG) for the control asphalt, 2.5%, 4.5% and 6.5% SBS are finalized as PG 64-XX, PG 70-XX, PG 76-XX and PG 88-XX respectively. Moreover, all the Asphalt binders achieved the viscosity requirements of maximum 3 Ps.s except 6.5% SBS-modified asphalt binder.
Table 4. Summary of asphalt binder performance grading based on AASHTO

| Asphalt Binder                  | Control | 2.5% SBS | 4.5% SBS | 6.5% SBS |
|---------------------------------|---------|----------|----------|----------|
| Superpave High Performance Grade| 64      | 70       | 76       | 88       |
| Original DSR G*/sinδ (kPa)      | 1.45    | 1.67     | 2.85     | 1.93     |
| AASHTO Limits                   | 1.00    | 1.00     | 1.00     | 1.00     |
| RTFO Residue DSR G*/sinδ (kPa)  | 3.41    | 3.29     | 3.63     | 2.40     |
| AASHTO Limits                   | 2.20    | 2.20     | 2.20     | 2.20     |
| Viscosity at 135 °C (Pa.s)      | 0.38    | 0.80     | 1.84     | 3.11     |
| AASHTO Limits                   | 3.00    | 3.00     | 3.00     | 3.00     |

5.7. Asphalt Binder Workability

Workability of an asphalt binder is a temperature range that can achieve the viscosity requirements for mixing and handling or laydown and compaction. According to ASTM D2493 [45] the mixing range is (0.17±0.02 Pa.s) and the compaction range is (0.28±0.03 Pa.s). Figure 6 presents the mixing and compaction ranges for all the tested asphalt binders. Figure 6 includes the viscosity verses temperature curves for all tested asphalt binders with mixing and compaction ranges.

![Figure 6. Mixing and compaction ranges for all the asphalt binders](image)

Table 5 shows the mixing range, compaction range, mixing workability, delivery limit and compaction workability for control and SBS-modified asphalt binder. Mixing workability is the difference between the upper and the lower limits of the mixing range while the compaction workability is difference between the upper and the lower limits of the compaction range. As shown in Table 5, SBS-modified asphalt binder exhibited a high mixing and compaction ranges. In general, the asphalt binder that has a higher viscosity, a higher softening point, better temperature stability, or a
more sufficient viscosity at high temperature can result in a mix that will maintain a certain level of strength and stiffness without a significant shear deformation at high temperature.

| asphalt binder | Mixing Range | Compaction Range | Mixing Workability | Delivery Limit | Compaction Workability |
|----------------|--------------|------------------|--------------------|----------------|-----------------------|
| Control        | 156.92       | 151.33           | 139.04             | 134.97         | 5.59                  | 12.29                | 4.07               |
| 2.5% SBS       | 174.18       | 168.55           | 156.20             | 152.10         | 5.63                  | 12.35                | 4.10               |
| 4.5% SBS       | 191.42       | 185.99           | 174.10             | 170.15         | 5.43                  | 11.89                | 3.95               |
| 6.5% SBS       | 199.83       | 194.73           | 183.54             | 179.83         | 5.10                  | 11.19                | 3.71               |

6. Conclusion
This paper investigated the effect of using SBS at 2.5, 4.5 and 6.5% by weight of asphalt binder on its properties and grading according to the penetration grading system and the Superpave asphalt binder classification system. The testing plan included the penetration, softening point, RV, and DSR tests. The following conclusions can be drawn based on the analysis of the test results obtained for the control and SBS-modified asphalt binders:

- Increasing the SBS polymer content has led to lower penetration values and higher softening point and RV values.
- As the SBS polymer content increased, the G*/Sin δ values increased for both unaged and RTFO-aged SBS-modified asphalt binders.
- According to ASTM D946 grading system, 2.5% SBS polymer changed the asphalt binder penetration grade from 60/70 to 40/50 while achieving the softening point, RV and PI requirements.
- According to BS EN12591, 2.5% changed the asphalt binder grade from 50/70 to 40/60 while achieving the requirements of that grade. 4.5% and 6.5% SBS changed the grade to 35/50 and 30/45 respectively but they failed to achieve the softening point requirements.
- Adding SBS polymer contents of 2.5%, 4.5% and 6.5%, changed the high temperature PG grade of the asphalt binder from 64 to 70, 76 and 88 respectively. Only 6.5% SBS failed to comply with the maximum viscosity requirements.
- The mixing and compaction ranges increased with increasing SBS content. The ranges increased up to 45°C more compared to the control asphalt binder when 6.5% SBS was added. The mix design of asphalt concrete (AC) mixtures using SBS-modified asphalt binders to overcome expected workability issues that might be encountered due to increased compaction temperature.
- Further research should be done to investigate the effect of adding SBS on the low temperature PG and to assess the fatigue performance of SBS-modified asphalt binders.

Acknowledgement
The authors would like to thank Sharjah research academy for sponsoring this project. The authors would acknowledge the effort of Eng. Ayat Gamal for helping out in some of the penetration tests. Special thanks also to Dr. Hanqi for his help. Thanks to Eng.Leticia Rodriguez from Mena Energy for providing the asphalt binder samples.

7. References
[1] Sabouni, R., & Alghazali, A. (2014). Polymer modified asphalt binder asphalt, a proposed solution for UAE pavement deterioration. Construction Materials and Structures, September 2016, 620–628.
[2] King G et al. Additives in asphalt. J Assoc Asphalt Paving Technol A 1999;68:32–69.
[3] Yousefi A. Rubber-polyethylene modified mitumens. Iran Polym J 2004;12:101–12.
[4] Ahmedzade P, Yilmaz M. Effect of polyester resin additive on the properties of asphalt binders and mixtures. Constr Build Mater 2008;22:481–6.

[5] Gorkem C, Sengoz B. Predicting stripping and moisture induced damage of asphalt concrete prepared with polymer modified asphalt binder and hydrated lime. Constr Build Mater 2009;23(6):2227–36.

[6] Airey GD. Rheological evaluation of ethylene vinyl acetate polymer modified asphalt binders. Constr Build Mater 2002;16:473–87.

[7] Brovelli, C., M. Crispino, J. Pais, and P. Pereira. 2015. “Using polymers to improve the rutting resistance of asphalt concrete.” Constr. Build. Mater. 77 (2): 117–123.

[8] Cardone, F., G. Ferrotti, F. Frigio, and F. Canestrari. 2014. “Influence of polymer modification on asphalt binder dynamic and steady flow viscosities.” Constr. Build. Mater. 71 (11): 435–443.

[9] Yildirim, Y. 2007. “Polymer modified asphalt binders.” Constr. Build. Mater. 21(1): 66–72.

[10] Zhu, J., B. Birgisson, and N. Kringos. 2014. “Polymer modification of asphalt binder: Advances and challenges.” Eur. Polym. J. 54 (5): 18–38.

[11] John, R., and D. Whiteoak. 2003. Shell asphalt binder handbook. London, UK: Thomas Telford.

[12] Ahmedzade, P. (2013). The investigation and comparison effects of SBS and SBS with new reactive terpolymer on the rheological properties of asphalt binder. Construction and Building Materials, 38, 285–291.

[13] A. Behnood, A. Shah, R.S. McDaniel, M. Beeson, J. Olek, High temperature properties of asphalt binders: Comparison of multiple stress creep recovery and performance grading systems, Transp. Res. Rec. J. Transp. Res. Board. 2574 (2016) 131–143

[14] B.V. Kök, H. Çolak, Laboratory comparison of the crumb-rubber and SBS modified asphalt binder and hot mix asphalt, Constr. Build. Mater. 25 (8) (2011) 3204–3212.

[15] S. Tayfur, H. Ozen, A. Aksoy, Investigation of rutting performance of asphalt mixtures containing polymer modifiers, Constr. Build. Mater. 21 (2) (2007) 328–337.

[16] A. Mokhtar, F. Moghadas Nejad, Mechanistic approach for fiber and polymer modified SMA mixtures, Constr. Build. Mater. 36 (2012) 381–390.

[17] S. Anjan kumar, A. Veeraragavan, Dynamic mechanical characterization of asphalt concrete mixes with modified asphalt binders, Mater. Sci. Eng. A. 528 (21) (2011) 6445–6454.

[18] H. Aglan, A. Othman, L. Figueroa, R. Rollings, Effect of styrene–butadiene styrene block copolymer on fatigue crack propagation behavior of asphalt concrete mixtures, Transp.Res. Rec. 1417. 1417 (1993) 178–186.

[19] R. Lundström, U. Isacsson, Linear viscoelastic and fatigue characteristics of styrene–butadiene–styrene modified asphalt mixtures, J. Mater. Civ. Eng. 16 (6) (2004) 629–638.

[20] T.W. Kim, J. Baek, H.J. Lee, J.Y. Choi, Fatigue performance evaluation of SBS modified mastic asphalt mixtures, Constr. Build. Mater. 48 (2013) 908–916.

[21] K.W. Kim, S.J. Kweon, Y.S. Doh, T.-S. Park, Fracture toughness of polymer-modified asphalt concrete at low temperatures, Can. J. Civ. Eng. 30 (2) (2003) 406–413.

[22] S. Ho, L. Zanzotto, The low temperature properties of conventional and modified asphalt binders evaluated by the failure energy and secant modulus from direct tension tests, Mater. Struct. 38 (1) (2005) 137–143.

[23] B. Kök, M. Yilmaz, A. Geçkil, Evaluation of low-temperature and elastic properties of crumb rubber– and SBS-modified asphalt binder and mixtures, J. Mater. Civ. Eng. 25 (2) (2013) 257–265.

[24] E. Iskender, A. Aksoy, H. Ozen, Indirect performance comparison for styrene–butadiene–styrene polymer and fatty amine anti-strip modified asphalt mixtures, Constr. Build. Mater. 30 (2012) 117–124.

[25] C.E. Sengul, S. Oruc, E. Iskender, A. Aksoy, Evaluation of SBS modified stone mastic asphalt pavement performance, Constr. Build. Mater. 41 (2013) 777–783.

[26] Yildirim, Y. (2007). Polymer modified asphalt binders. Construction and Building Materials, 21(1), 66–72.

[27] Bru`le`, B.; Brion, Y.; Tanguy, A. Asphalt Paving Technology: Proceedings. Association of Asphalt Paving Technologists, Technical Sessions, 1988, 57, 41
[28] Airey, G. (2003). Rheological properties of styrene butadiene styrene polymer modified road bitumens. Fuel, 82(14), 1709–1719.

[29] Sengoz, B., & Isikyakar, G. Analysis of styrene-butadiene-styrene polymer modified asphalt binder using fluorescent microscopy and conventional test methods. Journal of Hazardous Materials, 150(2)(2008) 424–432.

[30] Sengoz, B., & Isikyakar, G. Evaluation of the properties and microstructure of SBS and EVA polymer modified asphalt binder. Construction and Building Materials, 22(9) (2008) 1897–1905.

[31] Hassanpour-Kasanagh, S., Ahmedzade, P., Fainleib, A. M., & Behnood, A. Rheological properties of asphalt binders modified with recycled materials: A comparison with Styrene-Butadiene-Styrene (SBS). Construction and Building Materials, 230(2020)117047.

[32] Airey, G. D. Rheological properties of styrene butadiene styrene polymer modified road asphalt binders. Fuel, 82(14) (2003)1709–1719.

[33] Gama, D. A., Rosa, J. M., De Melo, T. J. A., & Rodrigues, J. K. G. Rheological studies of asphalt modified with elastomeric polymer. Construction and Building Materials, 106, (2016)290–295.

[34] Ahmedzade, P. The investigation and comparison effects of SBS and SBS with new reactive terpolymer on the rheological properties of asphalt binder Position of. Construction and Building Materials, 38,(2013) 285–291.

[35] Sengoz, B., & Isikyakar, G. (2008). Analysis of styrene-butadiene-styrene polymer modified asphalt binder using fluorescent microscopy and conventional test methods. Journal of Hazardous Materials, 150(2), 424–432.

[36] Behnood, A., & Olek, J. Rheological properties of asphalt binders modified with styrene-butadiene-styrene (SBS), ground tire rubber (GTR), or polyphosphoric acid (PPA). Construction and Building Materials, 151,(2017) 464–478.

[37] Mielczarek M, Słowik M, Andrzejczak K. The assessment of influence of styrene-butadiene-styrene elastomer’s content on the functional properties of asphalt binders. Eksplotacja i Niezawodnosc – Maintenance and Reliability 2020; 22 (1)(2020) 148–153.

[38] ASTM D7175-08, Standard Test Method for Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer, ASTM International, West Conshohocken, PA. 2008.

[39] ASTM D5-06, Standard Test Method for Penetration of Bituminous Materials, ASTM International, West Conshohocken, PA. 2006.

[40] ASTM D36-95e1, Standard Test Method for Softening Point of Asphalt binder (Ring-and-Ball Apparatus), ASTM International, West Conshohocken, PA. 2001.

[41] ASTM D4402 / D4402M-15, Standard Test Method for Viscosity Determination of Asphalt at Elevated Temperatures Using a Rotational Viscometer, ASTM International, West Conshohocken, PA. 2015.

[42] ASTM D946 / D946M-20, Standard Specification for Penetration-Graded Asphalt Binder for Use in Pavement Construction, ASTM International, West Conshohocken, PA, 2020, www.astm.org

[43] BS EN 12591:2009 Asphalt binder and bituminous binders - specifications for paving grade asphalt binders (incorporating corrigendum June 2011)

[44] AASHTO M 320-17 Standard Specification for Performance-Graded Asphalt Binder STANDARD by American Association of State and Highway Transportation Officials, 2017

[45] ASTM D2493 / D2493M-16, Standard Practice for Viscosity-Temperature Chart for Asphalt Binders, ASTM International, West Conshohocken, PA, 2016, www.astm.org