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Original Article

Determination of Rutting Resistance of SBS and Warm Asphalt Additive Binders by the MSCR Test

Mustafa Akpolat

Department of Civil Engineering, Munzur University, Tunceli, Türkiye.

Corresponding Author : mustafaakpolat@munzur.edu.tr

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Abstract *- The MasterLife PAV110 Warm Mix Asphalt (WMA) additive's rutting resistance in pure and Styrene-Butadiene-Styrene (SBS)-modified binders was examined using MSCR testing. Multiple Stress Creep Recovery (MSCR) tests were conducted on seven binders. The study's findings indicated that the incorporation of WMA resulted in an increase in the Jnr values of both pure binders and binders modified with SBS at stress levels of 0.1 and 3.2 kPa. This finding implies that the occurrence of rutting will be negatively impacted. On the other hand, the performance level categorization showed that WMA additives had no impact on the performance levels of pure and SBS-modified binders. Since the Jnr and average percentage Recovery (R) values at 3.2 kPa, 1%, and 1.5% PAV110 additives exhibited similar properties, it was determined that the optimum usage rate in terms of cost was 1%.*

Keywords *- Warm mix asphalt, Modification, Rutting, MSCR test.*

1. Introduction

Due to the increasing energy costs of Hot Mix bituminous Asphalt (HMA) produced at high temperatures, the need to reduce emissions in environmental and climate assessments, and the aging of bitumen, researchers have started investigating mixtures produced at lower temperatures. Technologies for warm-mix asphalt can successfully cut down on energy use and pollutants [1, 2]. As a result, different methods for producing warm mixed asphalt have been developed. In order to achieve reduced production temperatures, three different WMA technologies are employed. These comprise chemical additions, wax-based additives, and foaming processes that are either water-based or contain water [3]. It is reported that using WMA technology can reduce the environmental impact by 33% compared to HMA [4]. The choice of asphalt binders to be included in the mixtures is made per the superpave standard, which considers the local climate and traffic patterns. Using the rutting parameter ($G^*/\sin\delta$) to determine the high-temperature Performance Grade (PG) is common practice. However, the study argued that it does not sufficiently define binders that have been changed with polymers [5]. Therefore, the Multi-Stress Creep Recovery (MSCR) test, which is reported to have a better correlation between rutting and superpave specification criteria [6], has started to be frequently used in studies. The MSCR test was developed to determine creep compliance (Jnr) and percentage Recovery (R), which are particularly useful for modified asphalt binders [7].

The rutting resistance of WMA and HMA mixtures was investigated with 83 field samples gathered from 28 field projects encompassing four climate zones in the United States. As a result of long-term aging, it was determined that binders obtained from WMA mixtures gave similar rutting resistance to binders obtained from HMA mixtures. It was also emphasized that an average of 66.89% can reduce CO2 emissions using WMA technology [8].

The MSCR test results were investigated in a study that used Polypropylene wax as a warm asphalt additive in conjunction with Crumb Rubber (CR). It was reported that polypropylene wax could improve the rutting resistance of CR-modified binder with lower Jnr3.2 and higher %R values [9].

The viscosity of Styrene-Butadiene-Styrene (SBS) modified binder decreased with the inclusion of heated asphalt additives such as Sasobit or Rediset, according to a study looking at the usage of WMA additives in mixtures including modified asphalt binder [10]. Rutting resistance has also been observed to be increased by SBS-modified binders when Deurex [11] and Sasobit [10] are added.

In the study investigating the effect of warm asphalt additives on rutting (with MSCR test) and fatigue parameters (with LAS test) of nano-material modified binders, it was stated that warm asphalt additives improved the rutting resistance and fatigue performance of the binder. It was also reported that warm asphalt additives improved the aging performance of nano-modified asphalt binders [12].

Two different chemical warm asphalt additives (Evotherm M1 and Iterlow T) were added to crumb rubber-modified binders, and the rheological properties of the binders were investigated. According to the results obtained, it was noted that CR increases the hardness of the binder and gives a high softening point and rutting resistance. Still, WMA technology reduces the stiffness and performance of asphalt at high temperatures [13].

Chemical additives had the potential to enable low-temperature production due to their ability to decrease the resistance at the aggregate and bitumen interface. Additionally, these additives facilitated an improved aggregate coating rather than directly reducing the viscosity.

Warm mix additives used as anti-stripping additives do not significantly affect the binder's viscosity, although they are used in low dosages. However, they have been reported to significantly reduce rutting and improve rutting and fatigue cracking at low temperatures. Evotherm, a chemical warm mix admixture, has been reported to improve workability by enabling mixing and compaction at low temperatures and increasing the mix's peel resistance by improving the adhesion properties of the binder [14, 15].

This study evaluated the effects of PAV110, a chemical WMA additive, and the commonly used SBS additive, separately and together, on the creep compliance (Jnr) and creep reversal (%R) values of the binders.

2. Materials and Methods

2.1. Materials

The experimental plan is given in Figure 1. BASF's MasterLife PAV110 warm mix asphalt additive and Kraton's SBS additive were used as additives. All modified binders were prepared with pure binders of penetration class B 50/70 obtained from the TÜPRAŞ refinery using the mechanical mixer.

The usage rates of the additives used in the study are also shown in Figure 1. The modified binders were prepared by mixing at a speed of 1000 rpm and a temperature of 170°C for 1 hour. In order to prevent discrepancies between binders caused by aging during mixing, pure binders were also put through the same mixing procedure. The properties of the MasterLife PAV110 additive are listed in Table 1.

Table 1. Technical characteristics of the master life PAV110 additive

Technical Properties	
View	Dark brown liquid
Density (at 20°C)	0.89-0.92 kg/lt
Boiling point (15% solution-760 mmHg)	350°C
Flashpoint (open cup)	150°C
Viscosity (cps@40°C)	8-40

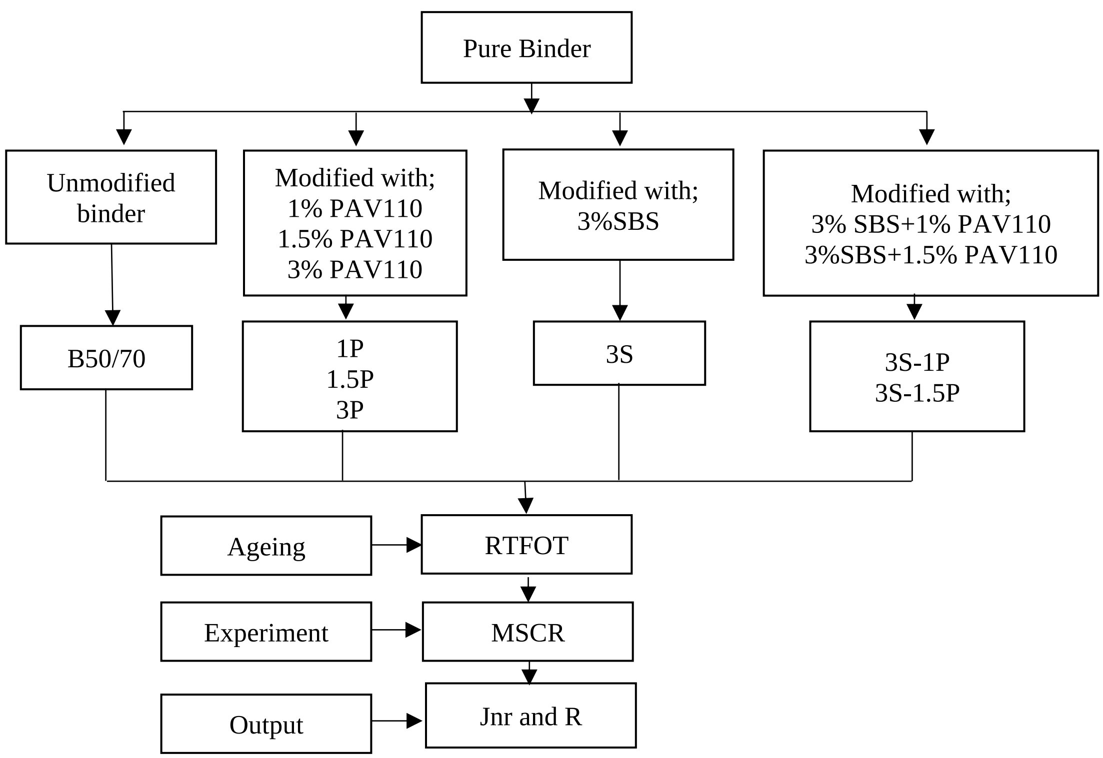

Fig. 1 Experimental plan

2.2. Method

2.2.1. MSCR Test

In line with AASHTO T350 [16], the MSCR test on RTFOT residue was carried out at temperatures ranging from 52 to 70°C (increasing by 6°C) using a 25-mm plate with pure and modified binders. Twenty cycles of 0.1 kPa stress and ten cycles of 3.2 kPa stress were applied during the test at various temperatures. One second of shear stress and nine seconds of recuperation make up each cycle. A binder's activity in the linear viscoelastic zone is characterized by a shear stress of 0.1 kPa, whereas modified and pure binders exhibit nonlinear viscoelastic behavior at a stress level of 3.2 kPa.

According to AASHTO M332, two parameters are acquired from the MSCR test. These are permanent creep compliance (Jnr) numbers and percent Recovery (R). Equations 1 and 2 are used to find the average percent recovery values for asphalt binder at shear stress levels of 0.1 kPa (R0.1) and 3.2 kPa (R3.2) kPa, respectively [15].

$$R_{0.1} = \frac{\sum_{N=11}^{20}[\varepsilon_r(0.1,N)]}{10} \quad (1)$$

$$R_{3.2} = \frac{\sum_{N=1}^{10}[\varepsilon_r(3.2,N)]}{10} \quad (2)$$

In the formula, (0.1, N) and (3.2, N) are the percent recovery at 0.1 and 3.2 kPa stress levels at N number of cycles, respectively, and N is the number of cycles at each stress level.

The percent Recovery (R) measure is not currently used as a rating parameter, according to the AASHTO M332 standard [17, 18]. This characteristic, however, is utilized to determine whether altered admixtures are present in the binder. Unlike the Superpave PG criteria, the Jnr parameter was discovered to correlate better with rutting resistance [6, 19]. The permanent creep compliance at 3.2 kPa for a certain traffic level and the difference between the permanent creep compliance at 0.1 kPa and 3.2 kPa stress (Jnrdiff), with a maximum value of 75%, are used to determine the binder categorization technique.

The four different traffic loading classifications taken into account by the standard are Standard (S), Heavy (H), Very heavy (V), and Extremely heavy (E). Equations 3 and 4 provide the results of the computation of the permanent creep compliance values for 0.1 kPa (Jnr0.1) and 3.2 kPa (Jnr3.2), while Equation 5 reveals the results of the computation of the Jnrdiff value.

$$Jnr_{0.1} = \frac{\sum_{N=11}^{20}[Jnr(0.1,N)]}{10} \quad (3)$$

$$Jnr_{3.2} = \frac{\sum_{N=1}^{10}[Jnr(3.2,N)]}{10} \quad (4)$$

$$Jnr_{diff} = \frac{(Jnr(3.2)-Jnr(0.1))}{Jnr(0.1)} * 100 \leq 75 \quad (5)$$

3. Result and Discussion

The creep compliance (Jnr) values of pure and modified binders at 0.1 kPa are given in Figure 2. According to Figure 2, only adding the warm asphalt additive to the pure binder increased the Jnr values. This increase is 56.9%, 41.3%, and 121.9% for 1P, 1.5P, and 3P at 52 °C and 36%, 19.1%, and 73.9% at 70 °C, respectively. A significant decrease in Jnr values was achieved by adding SBS to the pure binder. This decrease is 3.13 times greater at 52°C and 4.1 times greater at 70°C. The use of warm asphalt additives together with SBS slightly increased the Jnr values compared to SBS-modified binders. When Jnr values of 0.1 kPa were examined, it was discovered that using the warm asphalt additive alone reduced the rutting resistance of the pure binder. However, while adding SBS significantly increased rutting resistance, adding warm asphalt additive to SBS caused a slight decrease in resistance.

The creep compliance (Jnr) values of pure and modified binders at 3.2 kPa are detailed in Figure 3. According to the graph, warm asphalt additive causes an increase in Jnr values. This increase is 1.68, 1.44, and 2.28 times for 1P, 1.5P, and 3P at 52 °C and 1.34, 1.20, and 1.79 times at 70 °C, respectively. Jnr values were significantly reduced after SBS was added to the pure binder. At 52 °C, 58 °C, 64 °C, and 70 °C, this drop is 3.19, 3.91, 3.81, and 4.1 times greater, respectively. As the temperature increased, the Jnr values of the SBS additive increased compared to a pure binder.

This observation indicates that SBS additives provide better rutting resistance at higher temperatures. The use of warm asphalt additive with SBS slightly increased the Jnr values compared to SBS-modified binders, as demonstrated in the Jnr results at 0.1 kPa

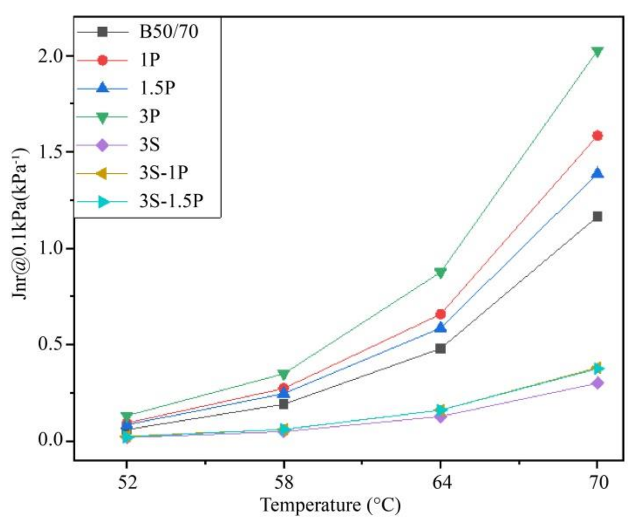

Fig. 2 Jnr values at 0.1 kPa

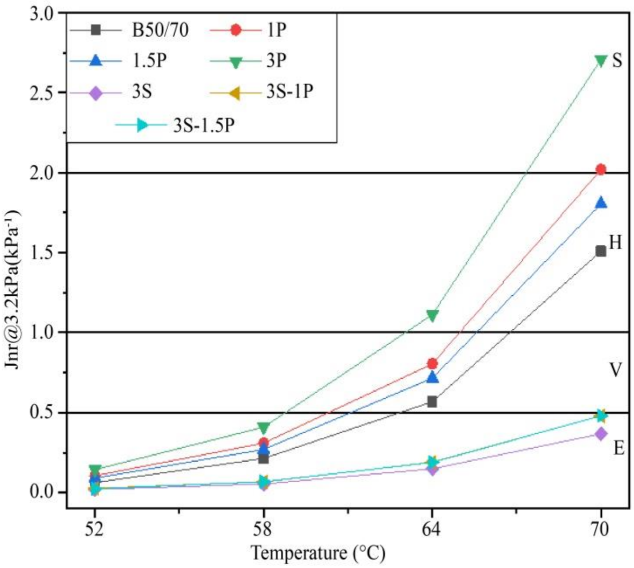

Fig. 3 Jnr values at 3.2 kPa

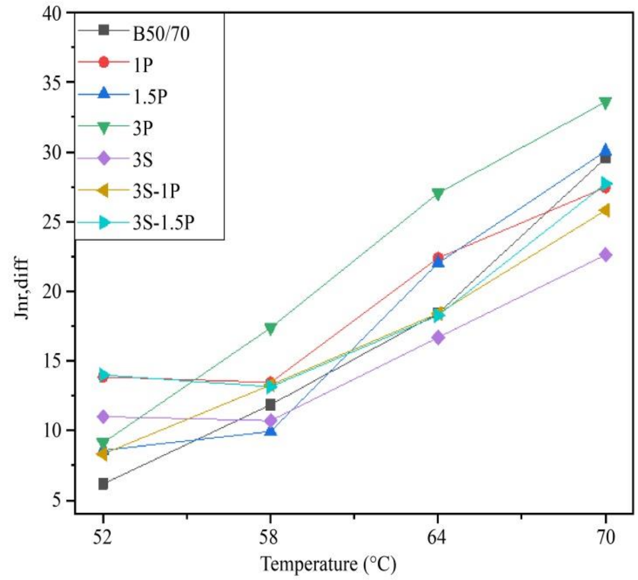

Fig. 4 Jnr, diff values at different temperatures

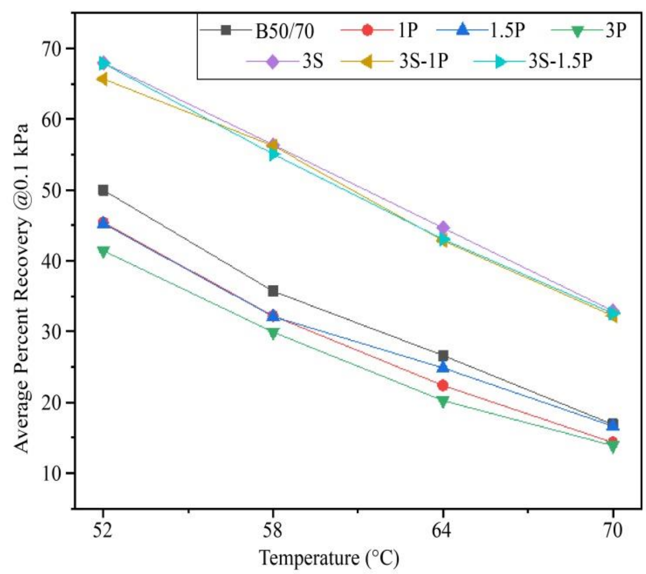

Fig. 5 Average percent recovery values at different temperatures

The 3S-1P and 3S-1.5P modified binders provided Jnr values about three times lower than the pure binder. When the Jnr values at 3.2 kPa were evaluated, it was determined that using warm asphalt additive alone decreased the rutting resistance of the pure binder. However, while adding SBS significantly increased the rutting resistance, adding the warm asphalt additive in SBS caused a slight decrease in this resistance. The best rutting resistance was obtained with a 3% SBS binder. In comparison, using 1% or 1.5% warm asphalt additive with 3% SBS provided a 0.5 kPa-1 value, the specification criterion for extremely heavy traffic.

Jnr, diff values of pure and modified binders at different temperatures are presented in Figure 4. Because Jnr, diff is the percentage ratio at 0.1 kPa and 3.2 kPa stress levels, it is possible to determine how stress changes affect the binders. According to Figure 4, all binders met the specification criterion of a maximum of 75%. With increasing temperatures, the tensile sensitivity of the pure binder increases approximately linearly. When the test temperature was increased from 52ºC to 58ºC, 1P, 1.5P, 3S, and 3S-1.P doped binders were not affected by the increase in stress-the Jnr. Diff values of warm asphalt doped binders increased as the test temperature increased.

With the increase in temperature from 64ºC to 70ºC, Jnr, the diff values increased by 60.5%, 22.6%, 36.5%, 24.3%, 35.5%, 40.3%, and 51.7% for all binders, respectively. Accordingly, the lowest increase was in the 1P and 3S binders. The graph shows that the SBS-modified binder produced the lowest Jnr, diff values after 58 °C. The lowest Jnr and diff values were obtained with SBS and a warm asphalt-modified binder. It was determined that using SBS and warm asphalt additives will ensure that the pure binder will be less affected by the stress change, especially at 70 °C.

Figures 5 and 6 show the average percent recovery at different temperatures of 0.1 and 3.2 kPa. According to Figure 5, it is highlighted that all binders exhibit similar properties at both stress levels. At a 0.1 kPa stress level, there was no difference in the recovery percentage between SBS and SBS with warm asphalt additives.

Still, as the stress level increased to 3.2 kPa, SBS-modified binders exhibited more flexibility by giving a higher recovery percentage. This finding indicates that they can withstand deformations for a longer period. In the case of using warm asphalt additives alone, they exhibited more viscous behavior at both stress levels, giving lower percentages of recovery than a pure binder.

At a 0.1 kPa stress level, increasing the test temperature from 52°C to 70°C decreased the average percentages of recovery by about three times for B50/70, 1P, 1.5P, and 3P, while this ratio decreased by up to a factor with the use of SBS and SBS with warm asphalt. The same situation decreases from about nine times to three times at a 3.2 kPa stress level.

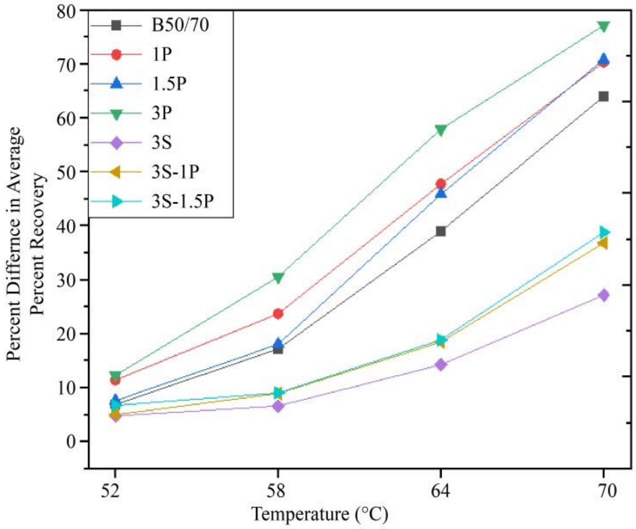

Fig. 6 Average percent recovery values at different temperatures

In other words, binders with SBS and warm asphalt additives exhibited more flexible behavior at higher stress levels. This performance is also seen in the graph of the percentage difference in the average percentage of recovery at 3.2 kPa and 0.1 kPa, given in Figure 7. High-temperature performance levels of binders according to AAHTO M320 [16] and AASHTO M332 [15] standards are given in Table 2.

Based on the classification specified by AAHTO M320, the 3P admixture decreased the performance level of the binder by one degree. In addition, 1P and 1.5P warm asphalt additives reduced the performance level of the modified binder with the 3% SBS additive by one degree.

According to the AASHTO M332 specification classification, at 52 °C and 58 °C, all binders were found to be suitable for Extreme heavy (E) vehicle traffic, while at 64 °C and 70 °C, only SBS and SBS with warm asphalt additives were found to be suitable for extreme heavy vehicle traffic. Binders with pure and warm asphalt additives are suitable for heavy vehicle traffic at 70 °C.

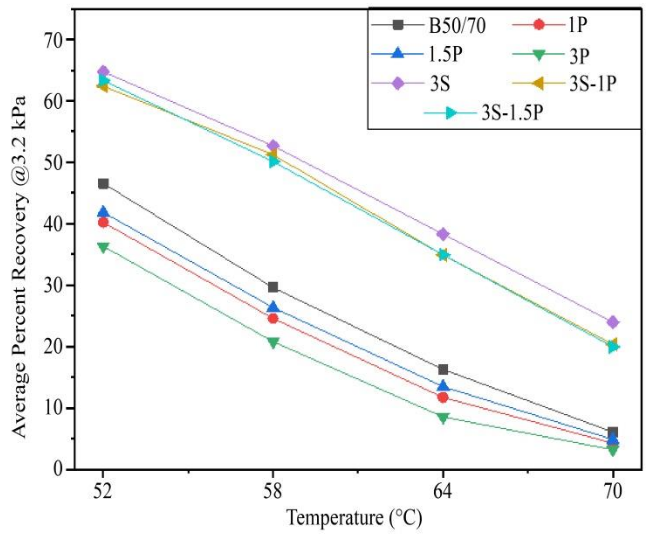

Fig. 7 Percent difference in average percent recovery values

Table 2. Binder high-temperature performance grades according to AASHTO M320 and AASHTO M332 specifications

Binder ID	**Grade Designation**				
	AASHTO M320	**AASHTO M332**			
B50/70	PG64	PG52E	PG58E	PG64V	PG70H
1P	PG64	PG52E	PG58E	PG64V	PG70H
1.5P	PG64	PG52E	PG58E	PG64V	PG70H
3P	PG58	PG52E	PG58E	PG64H	PG70S
3S	PG76	PG52E	PG58E	PG64E	PG70E
3S-1P	PG70	PG52E	PG58E	PG64E	PG70E
3S-1.5P	PG70	PG52E	PG58E	PG64E	PG70E

4. Conclusion

This study examined the rheological properties of warm asphalt additive in pure binder and binder modified with Styrene-Butadiene-Styrene (SBS) through the Multiple Stress Creep Recovery (MSCR) test. Additionally, the study aimed to evaluate the additive's resistance to rutting. Based on the findings acquired:

- The Jnr values of pure and SBS-modified binders were reduced by 0.1 kPa due to the heated asphalt additive utilized.
- At a 3.2 kPa stress level, SBS-modified binders gave the lowest Jnr values while providing the highest rutting resistance. Warm asphalt admixture with SBS caused an increase in Jnr values at a stress level of 3.2 kPa. However, it was established that this increase did not affect the material's classification under the AASHTO M332 criteria and was still appropriate for use in extremely heavy vehicle traffic.
- The inclusion of the warm asphalt additive resulted in a decrease in the average percent recovery values at both stress levels. This finding indicates that binders with warm asphalt additives exhibit more viscous behavior. Again, it was determined that SBS-modified binders exhibited more flexible behavior than other binders by giving the highest average percent recovery values.
- With the increase in the test temperature, the rate of decrease in the average percent recovery values of SBS and SBS-modified warm asphalt binders gradually decreased. This indicates that they may be more resistant to rutting at high temperatures.

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