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THE EFFECT OF SBR LATEX AND WARM MIX AGENT ON THE PERFORMANCE OF DRY AND WET ASPHALT MIXTURES

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ABSTRACT

Moisture damage has been identified as one of the most common causes of distress in asphalt mixes. The attachment between bitumen aggregate components deteriorates when water interacts at the interface, causing the binder to be stripped from the exterior of the aggregate and cohesive breakdown inside the asphalt binder. To reduce the moisture sensitivity of asphalt mixes, styrene-butadiene rubber (SBR) and antistripping warm mix additive (WMA) have been frequently utilized. Nevertheless, the application of SBR and WMA as a compound modifier has yet to be investigated thus this research aims to evaluate the influence of SBR and WMA i.e., ZycoTherm on the moisture resistance of asphalt mixtures. For this reason, several tests, including modified Lottman, resilient modulus, and dynamic creep, were used to assess the mechanical properties of the mixes in both wet and dry situations. The results found that the SBR improved the mechanical performance of the mixture in dry conditions, whereas using the ZycoTherm as a single modifier was more effective in improving the performance of the mix in dry conditions. However, the application of the compound modifier (SBR and ZycoTherm) could optimize the performance of asphalt mixtures in both conditions i.e., dry and wet.

KEYWORDS

SBR, ZycoTherm, WMA, HMA, Rutting, Moisture damage.

1. INTRODUCTION

Asphalt pavements are often subjected to numerous challenges and malfunctions. Moisture damage, or stripping, is a common issue with durability (Iwański et al., 2023). Water damage is often caused by repetitive traffic loads. Stripping occurs when water enters the aggregate and asphalt film, breaking the bonds of adhesion and causing the binder film to separate from the aggregate's surfaces (Wang et al., 2018). To prevent this issue, ensure the mixture contains sufficient asphalt binder and is compressed to create an impenetrable mixture (Sahip et al., 2023). Deterioration occurs in two phases: stripping and structural degradation under traffic load. Asphalt qualities impact aggregate, binder, and mastic performance at the interface (Susanto et al., 2019).

Numerous scholars and researchers in the field of pavement have claimed that different types of studies, including Marshall stability, resilient modulus, and indirect tensile tests, were appropriate for evaluating a mixture's moisture sensitivity (Kareem et al., 2023; Omar et al., 2020; Zou et al., 2023). In addition, it has been proposed that there are several approaches to strengthen mixes against moisture sensitivity. Among the suggested techniques, using asphalt binder modifiers can enhance the durability of asphalt mixes when exposed to moisture (Al-Fatlawi et al., 2023). Polymers and antistripping agents are effective additives in modifying the physical, chemical, and rheological characteristics of binders, making them ideal for asphalt mixes. There are two types of polymer modifiers are now employed: plastomer and elastomer (Enieb et al., 2021). The use of plastomer modifiers remains restricted because of their poor low-temperature elasticity (Zou et al., 2023, Eltwati et al., 2022). On the other hand, elastomers have been used widely to improve the viscosity, softening point, and adhesive bond of asphalt binders (Vamegh et al., 2020). As a result, asphalt pavement made with an elastomer-modified asphalt binder usually exhibits superior resistance to minimal-temperature cracking, moisture susceptibility, and fatigue damage (Radeef et al., 2022). Styrene-butadiene rubber (SBR) latex is one of those elastomer modifiers that is widely known for being effective and affordable (Han et al., 2022). According to some research, the incorporation of SBR latex increases the asphalt binder's moisture resistance of asphalt mixes. The homogeneous dispersion of SBR latex molecules in asphalt binder, creating an interconnected three-dimensional structure in asphalt binder, may be responsible for this enhancement (Han et al., 2022, Liu et al., 2021, Babagoli and Rezaei, 2022).

Another technique used to improve the asphalt mixture's resistance to moisture is the application of an antistripping agent into an asphalt binder (Babagoli and Rezaei, 2022). The antistripping agents are compounds formulated to enhance the chemical bond between the aggregates and the asphalt binder. They can be found in either a solid or liquid condition (Rani et al., 2022). However, other technologies, including ZycoTherm, have lately been presented as nanomaterials (Ameli et al., 2020). ZycoTherm is considered a chemical warm mix agent (WMA) that lowers the mixing and compaction temperature of asphalt mixes while improving the resistance of mixes to moisture degradation without adversely affecting other characteristics of asphalt mix, such as Marshall stability (Eltwati et al., 2023). Past studies have shown that ZycoTherm improves the thermal resistance and compatibility of polymer-modified asphalt, including rubber-modified asphalt (Ameri et al., 2018, Khani Sanij et al., 2019).

SBR-modified asphalt has low storage stability, but the storage stability of asphalt binders treated with polymers can be enhanced via ZycoTherm. Together, SBR latex and ZycoTherm have the potential to significantly modify asphalt binder. The adhesion properties of asphalt treated with SBR and ZycoTherm compounds, however, have not been completely and methodically studied. The adherence of asphalt to aggregate significantly impacts raveling distress, which is a critical issue for asphalt pavements. The present research aims to analyze the impact of SBR latex and ZycoTherm on asphalt binder adherence characteristics at various degrees. In addition, the current investigation compares the impact of combining SBR latex and ZycoTherm on moisture damage resistance, rutting resistance, and resilient modulus to conventional HMA mixes.

2. MATERIALS

2.1. Asphalt binder and aggregate

The base binder chosen for the present study was a 60/70 penetration-graded asphalt binder supplied by a local asphalt factory. The features of this binder are listed in Table 1. Crushed limestone aggregate with a nominal maximum size of 12.5 mm was adopted throughout the mixes. Table 2 depicts the aggregates' gradation. The ideal binder concentration for the samples was determined to be 4.0% air voids in the total volume of the mixes. The HMA samples were compacted using a Marshall compactor. Table 3 lists the volumetric characteristics and Marshall test findings that were used in this investigation.

Table 1. Attributes of the study's asphalt binders.

Properties	Value	Specification	Standard
Penetration at 25°C (dmm)	65.3	60-70	ASTM (2020a)
Softening point (°C)	54.1	52-60	ASTM (2020b)
Ductility (cm)	111	>100	ASTM (2017)
Viscosity at 135°C (mPa.s)	575	>230	ASTM-D4402 (2015)
Specific gravity	1.03	1.0-1.05	ASTM (2021)

Table 2. The aggregate gradation.

Sieve size (mm)	19.00	12.50	9.50	4.75	2.38	0.595	0.297	0.150	0.075
Passing %	100	91.2	70.8	55.3	42.3	26.4	16.6	7.8	4.9
Specification (ASTM-D3515, 2001)	100	80-100	60-80	48-65	35-50	19-30	13-23	7-15	3-8

Table 3. The volumetric properties and optimum binder content for mixtures.

Mixture	**Optimal asphalt content %**	**Volumetric properties**					
		VTM %	**VMA %**	**VFA %**	**Unit weight gm/cm3**	**Flow, mm**	**Stability, Kg**
HMA	6.02	4.00	14.2	71.79	2.31	3.1	1925
Specifications (ASTM-D6926, 2000)	3.5-7%	3-5%	Min 13%	65-75%	-	2-4mm	Min.816kg

2.2. Asphalt binder modifiers

The SBR latex-296 was obtained from a local supplier. It is a latex made of one component polymer. The product is a milky white liquid with a density of 1.015g/cm3. 4% of the total weight of asphalt binder was chosen for the SBR latex in this investigation, taking into account the results of earlier research (Xue et al., 2022, Li et al., 2021).

ZycoTherm is a liquid agent that is employed to enhance the resistance of binders against moisture. It produces silanol by hydrolysis in the presence of moisture. The asphalt binder converts it into hydrophobic siloxanes, whereas the organic component forms hydrogen bonds with the hydroxylated surface of the aggregates. The ZycoTherm additive with a flash point of 90°C and a viscosity of 400 CPS was utilized. The ZycoTherm utilized in the present research is depicted in Fig. 1. Several previous studies recommended that an amount of 0.1% of the total weight of asphalt binder should be selected for the ZycoTherm. Both of these additives were added to asphalt binder in wet method at 140°C and mixed for 30 min at 800 rpm rate of mixing.

Fig. 1. ZycoTherm and SBR latex additives.

3. TESTING METHODS

3.1. Indirect tensile strength (ITS) test (Modified Lottman test)

The tensile strength of mixes is a vital attribute that demonstrates the cohesion and adhesion characteristics of the binder and the aggregate-binder interactions, which leads to increased resistance to tensile strength in the asphalt. Blend durability against moisture degradation was evaluated employing the (AASHTO-T283, 2014) criterion. A compressive stress with a constant displacement rate of 50 mm/min at 25°C was used to achieve ITS according to AASHTO T322. Fig. 2 shows the test setup.

The tensile strength of the conditioned specimen divided by the unconditioned specimen yielded the tensile strength ratio (TSR). The TSR indicates a loss in mixture integrity due to moisture deterioration. TSR failure criteria have frequently been set at a minimum percentage of 80% (AASHTO-T283, 2014). The following method is used to compute the TSR values:

$$TSR = \frac{ITS\ (\text{conditioned})}{ITS\ (un\text{conditioned})} \times 100 \quad (1)$$

Fig. 2. ITS test setup.

3.2. Dynamic creep test

The development of WMA technology has prompted concerns about permanent deformation due to reduced stiffness and a probable decrease in stability in WMA mixes. The issue increases when the asphalt is exposed to moisture. To assess the impact of moisture on rutting results for HMA mixes containing modifiers i.e., WMA agent and SBR latex, the US. NCHRP 9-19 Superpave W2 dynamic creep experiment shown in Fig. 4 was applied to both unconditioned and conditioned samples at 50°C. A measurement was taken of the vertical cumulative permanent strain under compressive haversine load, possessing a 450 kPa deviating stress capacity. The number of load repetitions for which the slop of the curve is the minimum is defined as FN as shown in Fig. 3 (Walubita et al., 2013).The creep ratio (CR) was employed to evaluate the effect of moisture on rutting efficiency of mixtures, and the FN was determined for the conditioned and unconditioned specimens. Mixes with greater levels of CR are less vulnerable to moisture.

$$CR = \frac{FN(\text{conditioned})}{FN(unconditioned)} \times 100 \qquad (2)$$

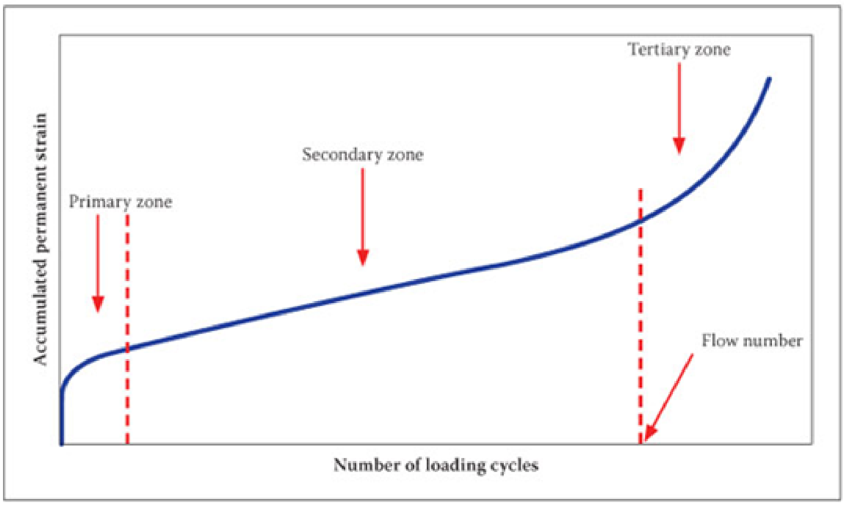

Fig. 3. Flow number determination

Fig. 4. Dynamic creep device.

3.3. Resilient modulus (Mr) test

The Mr of mixes was estimated using ASTM D 4123. The mixes were separated into two distinct groups. The first group of specimens remained dry at 25°C, while the other group was soaked in water according to AASTHO T283 and designated as the conditioned specimens. The device used for this test is shown in Fig. 5.

The Mr test uses a haversine pressure wave with the operation of loading and unloading times of 0.1 s at one hertz. Finally, the resilient modulus ratio (RMR) indicator (the proportion of wet to dry specimens) was assessed. RMR of 80% is frequently referenced as the minimum requirement for HMA mixtures (Obaid et al., 2022) (Ameli et al., 2021). The RMR values are determined in the following manner:

$$RMR = \frac{M_R\,(\text{conditioned})}{M_R\,(\text{unconditioned})} \times 100 \tag{3}$$

Fig. 5. Resilient modulus device.

4. RESULTS AND DISCUSSION

4.1. Indirect tensile strength (ITS) test (Modified Lottman test)

Fig. 6 shows the results of the ITS of the mixtures under two diverse situations. The results of this study displayed that for all mixtures, moisture has a significant effect on ITS values. This can result from either the breakdown of adherence of the aggregate exterior to the asphalt binder or the breakdown of cohesion of asphalt mixtures resulting from exposure to moisture. In dry conditions, the tensile strength values for HMA, HMA+SBR, HMA+ZycoTherm, and HMA+SBR/ZycoTherm were 0.825, 1.15, 0.92, and 0.995 MPa, respectively. After conditioning, these values were decreased as follows 0.655, 1.05, 0.9, and 0.928 MPa, respectively. The higher indirect tensile strength in the modified mixtures can be ascribed to the inclusion of harder binders or enhanced adhesive and/or cohesive strength resulting from the existence of ZycoTherm additives and the SBR. The effect of adding SBR on ITS results was higher than that of adding ZycoTherm or both owing to the occurrence of the polymeric network. Fig. 7 shows the average TSR values of all mixtures that meet the specified requirements except for HMA, which are set at a minimum of 80% according to the AASHTO T 283 standard. The mix with ZycoTherm showed enhanced resistance to moisture damage, as evidenced by a tensile strength ratio increase to 18.44% compared to HMA. Greater TSR values indicate lower susceptibility to moisture damage in polymer- and ZycoTherm-modified mixtures in comparison to their unmodified counterparts. This finding is consistent with findings reported in other studies (Mahpour et al., 2023, Eltwati et al., 2023).

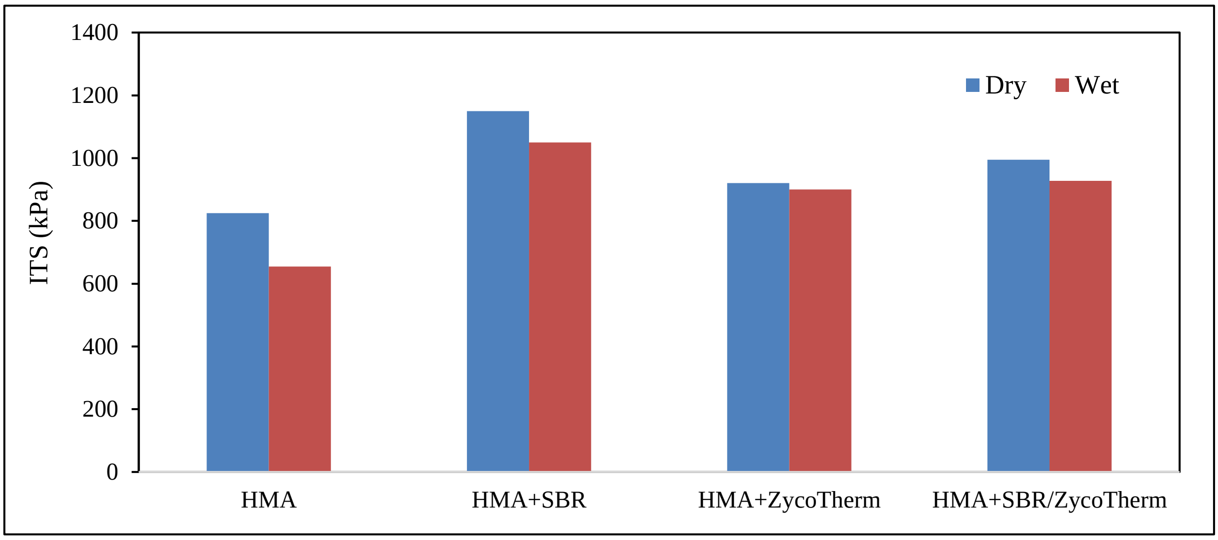

Fig. 6. ITS values of asphalt samples at dry and wet situations.

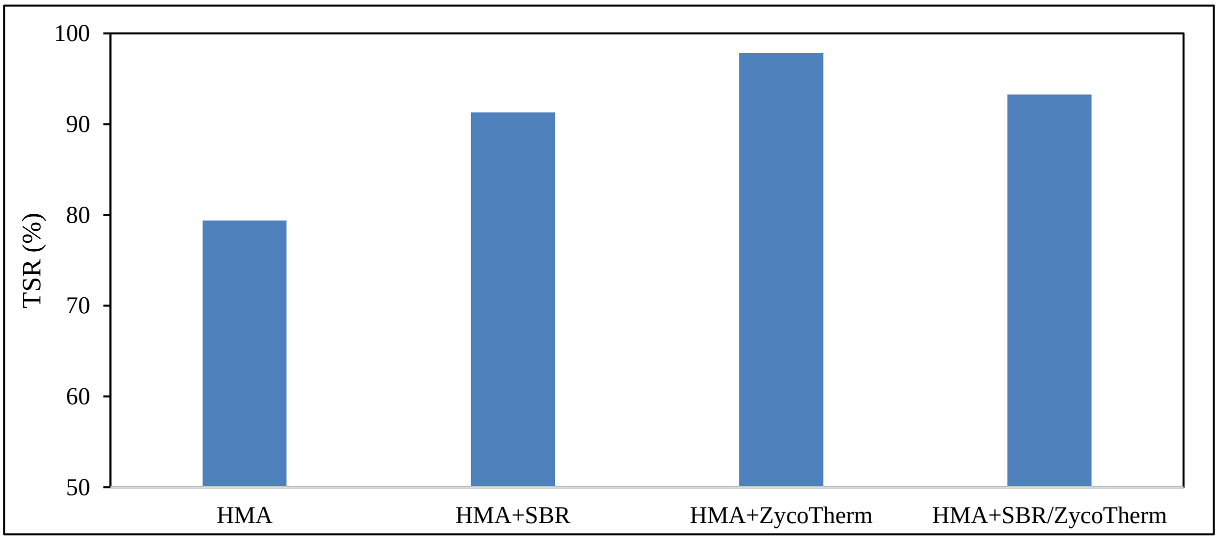

Fig. 7. Tensile strength ratio (TSR) of different asphalt mixtures.

4.2. Dynamic creep test

Fig. 8 and 9 display the outcomes of dynamic creep testing for various asphalt mixes. Dynamic creep test is widely used to evaluate rutting failure. Dynamic creep refers to the relationship between the applied load and the resulting deformation. The results depicted in Fig. 8 indicate that incorporating SBR into the binder rises the quantity of loading cycles necessary to achieve a specific amount of permanent displacement. This indicates that the SBR enhanced the mixture's resistance to rutting. As shown in Fig. 8, the addition of SBR has resulted in an approximately 14% increase in the flow number of HMA. This outcome is in line with the outcomes of previous studies (Hu et al., 2022, Mahpour et al., 2023). It can also be noted that

SBR and SRB/ZycoTherm additives increase the wet flow number of the HMA by 264% and 265%, respectively. The modified binder bonded to the aggregate after the addition of ZycoTherm is much tougher than the new combined binder.

Results shown in Fig. 9 show that under repeated load, the asphalt mixes modified with the WMA agent developed great rutting resistance against moisture. The HMA+SBR, HMA+ZycoTherm, and HMA+SBR/ZycoTherm mixtures exhibited more flow cycles than HMA. This is attributable to ZycoTherm, which improved asphalt adhesion to aggregates, and the FN was similarly influenced by the amount of strong SBR in the mix (Ameri et al., 2018). A previous study found that using ZycoTherm enhanced the FN of the asphalt mixture and thus reduced the potential of the asphalt mixture to rutting (Khani Sanij et al., 2019).

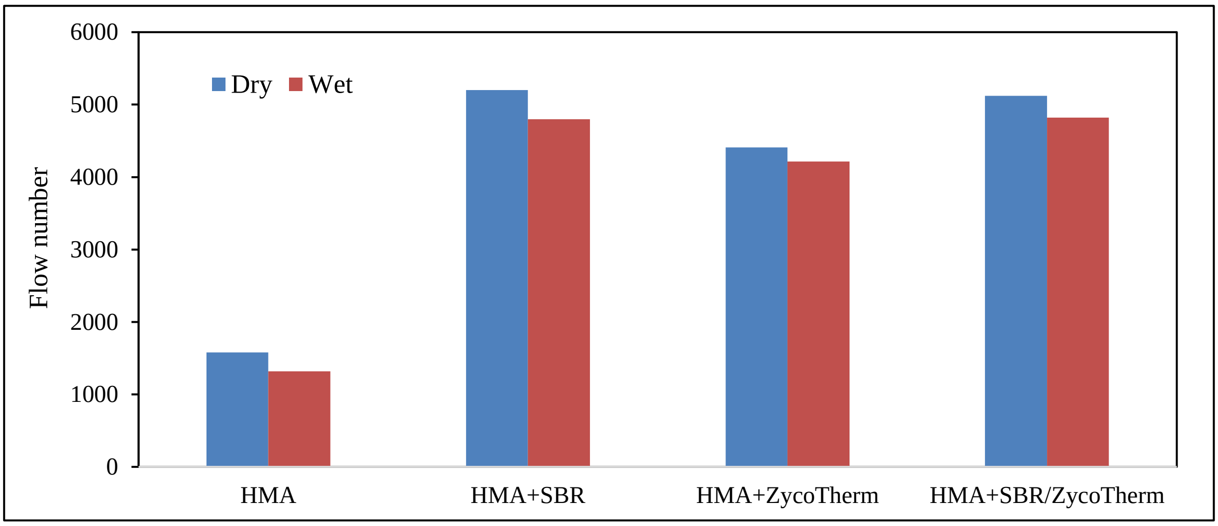

Fig. 8. Flow number for different asphalt mixtures.

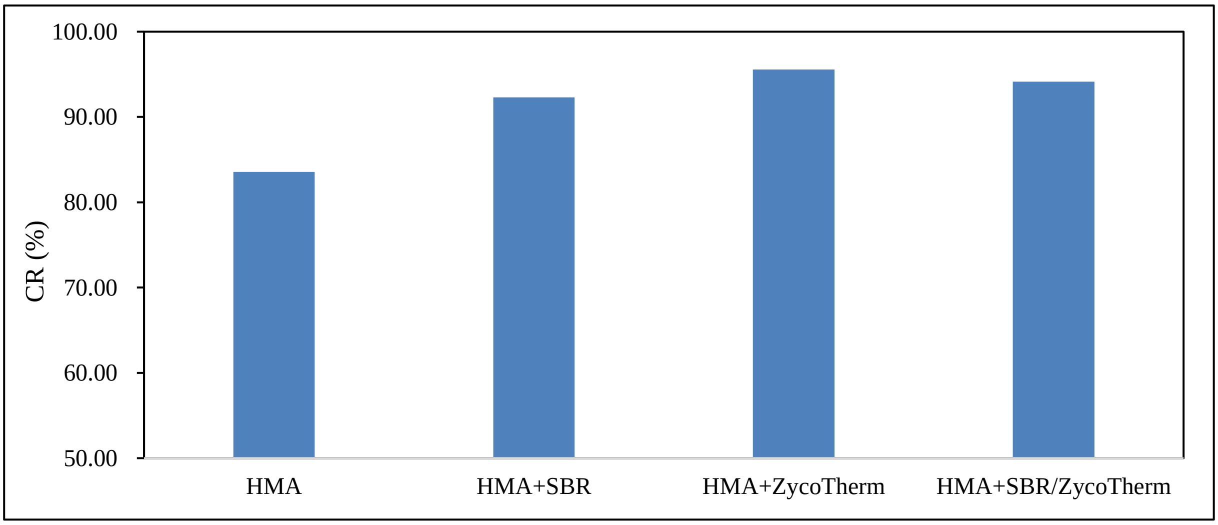

Fig. 9. The CR findings for mixtures.

4.3. Resilient modulus (Mr) test

Fig.10 shows the Mr for asphalt mixture specimens in wet and dry situations. In dry conditions, the resilient modulus values for HMA, HMA+SBR, HMA+ZycoTherm, and

HMA+SBR/ZycoTherm were 2.91, 3.71, 3.45, and 3.52 GPa, respectively. After conditioning, these values were 2.425, 3.395, 3.380, and 3.350 GPa, respectively. Furthermore, it was observed that the Mr values of modified mixture samples are higher than that of the HMA mixture in both conditions. It can also be seen that the effect of SBR was more effective than other additives i.e. Zycotherm; this was due to the decrease in viscosity. From the results, it can also be attributed that the SBR can be used with warm mixtures at lower mixing temperatures than hot mixtures, and provides a higher value for the Mr than a hot mixture without additives. Fig. 11 displays the resilient modulus ratio (RMR) of the mixtures. It can be seen that the WMA mixtures showed higher RMR values compared to the reference and other mixtures, demonstrating an enhanced resistance to moisture and cracking. Reduction in temperature while mixing for WMA mixes may contribute to a reduction in aging, thus could mitigate the likelihood of moisture penetration and cracking at the binder-aggregate contact through the treatment process (Guo et al., 2020, Babangida Attahiru et al., 2023).

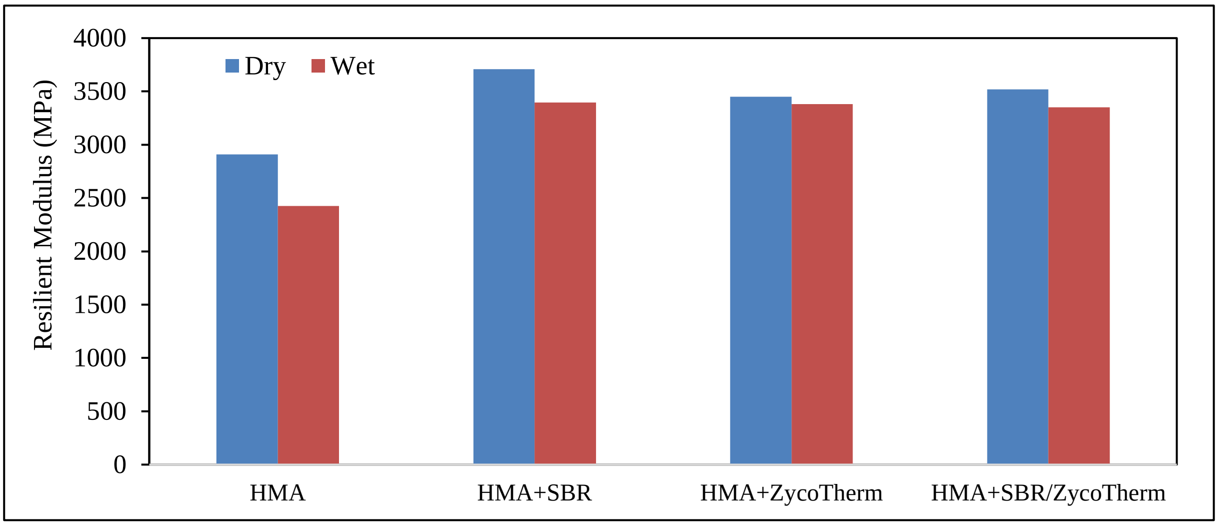

Fig. 10. Resilient Modulus results for different mixtures.

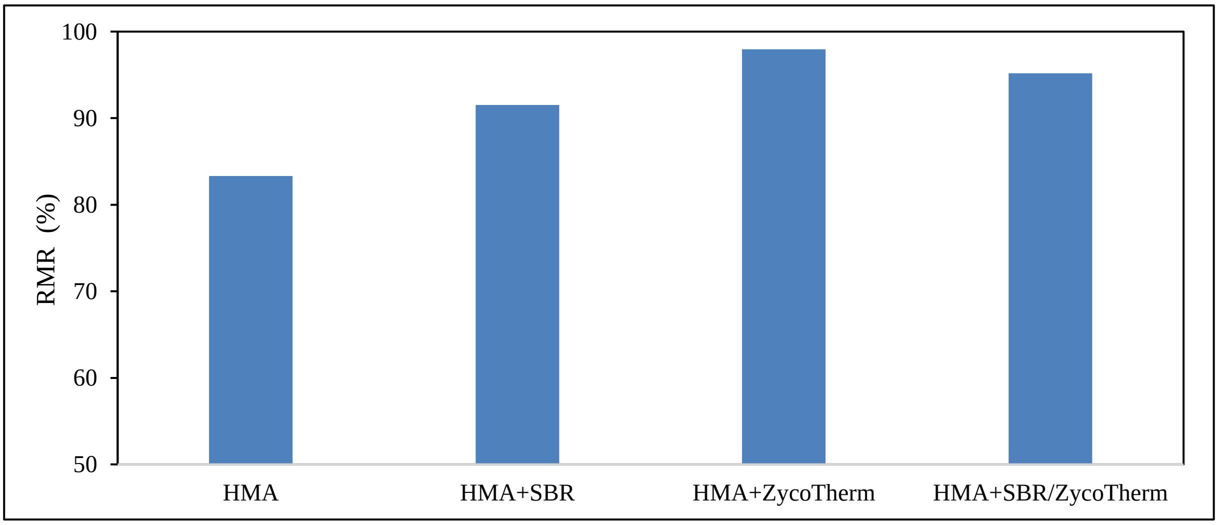

Fig. 11. Resilient Modulus ratio of wet to dry mixtures.

5. CONCLUSION

This study comprehensively assessed the performance of asphalt mixtures modified by ZycoTherm as WMA additive and SBR polymer. The performance evaluated includes tensile strength, susceptibility to moisture, dynamic creep behavior, and modulus of resilient performance. The experimental results and discussions highlight several advantages of SBR-modified warm mix asphalt with ZycoTherm as an environmentally friendly paving material. The main conclusions can be summarized as follows:

1. Modifying bitumen with SBR can enhance both the indirect tensile strength and the TSR index.
2. The asphalt mixtures modified by both ZycoTherm and SBR, and SBR-modified hot mix asphalt exhibted higher tensile strength compared to conventional HMA based on indirect tensile strength test findings.
3. Bitumen enhancement with SBR improves the indirect tensile strength of asphalt mixtures containing Zyco therm.
4. The incorporation of SBR has led to an approximately 14% enhancement to permanent deformation for the mixtures containing ZycoTherm.
5. Mixtures incorporating ZycoTherm show relatively higher values of ITS, TSR, Mr, RMR, and flow number.
6. The results indicate that the combination of SBR in a warm asphalt mixture with ZycoTherm positively affects rutting resistance, especially in the presence of moisture.

   In conclusion, SBR and ZycoTherm can be used at lower temperatures compared to hot mixtures, yielding good results for resistance to rutting and moisture.

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