Performance of Aged Asphalt Mastic Combining Active and Inert Filler Materials in Terms of Creep Recovery

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ABSTRACT

Mastic is the main component of an asphalt structure that deforms when stress is applied. Substantial research has been done on the deformation and creep and recovery characteristics of asphalt mastic with varying filler proportions to develop a rheological parameter. Few research, however, has examined the combined impact of active and inert fillers. This study compares the creep recovery performance of asphalt mastics fabricated with the combination of different active and inert fillers containing modifier and anti-stripping agent. To understand the creep recovery characteristics of aged asphalt mastic, an experimental campaign of Multiple Stress Creep Recovery (MSCR) tests following AASHTO T 350 was performed using the Dynamic Shear Rheometer (DSR). This investigation used Styrene-Butadiene-Styrene (SBS) as modifiers to modify the neat PG 58-28 binder and Zycotherm as liquid anti-stripping agent. For fabricating the mastics, different proportions (10%,20%,30% by the weight of base binder) of Hydrated lime (HL) and Fly ash (FA) were selected as active fillers, whereas different proportions (70%,60%,50% by the weight of base binder) of Limestone (LS), Dolomite (DM) and Basalt (Ba) were selected as inert filler materials. The active and inert fillers were added in such a way that the Filler-Binder (F/B) ratio remains 0.8. Rolling Thin-Film Oven (RTFO) protocol was applied to simulate construction and laying time oxidative aging. The performance of these mastics was compared using non-recoverable creep compliance, stress sensitivity analysis, and percent recovery analysis. AASHTO M 332 specifications have been used to classify all the mastics based on the J_{nr} value at 3.2 kPa and stress sensitivity. In addition, polymer method MSCR curve specified by the Asphalt Institute (AI) were employed to interpret the test results. Based on the analysis of experimental data, active filler HL produced better creep recovery performance compared to FA, and when combined with inert filler LS, it showed the best performance. The combined effect of 10%HL and 70%LS modified with SBS containing Zycotherm was predominant and satisfied all the creep recovery performance requirements.

Keywords: Asphalt mastic, Multiple Stress Creep Recovery, Active filler, Inert filler, Combined effect

INTRODUCTION

Inclusion of modifiers with binder, improves the binder's performance and reduces pavement distress (1). Polymer modifiers are the most effective strategy for preventing excessive plastic deformations at high temperatures (2). Furthermore, the aggregate surface is more attracted to water than binder due to its surface energy characteristics (3). Therefore, anti-stripping agents are added to the asphalt binder to combat moisture damage. With the inclusion of fillers with the binder, the cohesion between components formed mastic, where fillers influence the asphalt mixture by increasing the stiffness and altering the moisture resistance, workability, and compaction characteristics of asphalt mixtures (4-5). The component of the asphalt mixture known as the mastic deforms when stress is applied (6). Asphalt mastic is a combination of asphalt binder and specific ratios of mineral filler used to manage its mixture's mechanical behavior (7-8). Most of this mineral aggregate passes a 0.075 mm sieve (9). Mastic testing and research on the optimum filler-binder combination are subjects that are gradually garnering attention in this area and have demonstrated more potential than traditional binder testing (4,10).

A filler's function in an asphalt mixture may be divided into the following separate actions: 1) functioning as an inert filler material (Limestone (LS), Dolomite (DM), Basalt (Ba), etc.) to fill spaces between coarse aggregates, and 2) acting as an active filler material (Hydrated Lime (HL), Fly-ash (FA), diatomite) when it comes into contact with binder at the interface (11). Very few literature describe the combined effect of active and inert filler in modified asphalt mastic containing a liquid anti-stripping agent. The performance of the combination of active and inert filler in asphalt mastic will be evaluated in his study. When the proportion of active and inert filler is used above a specific limit, thermal cracking may develop. This is because the filler particles are cementing the binder too strongly. Thus, effective rutting resistance can only be achieved by using the proper quantity of filler (12). This investigation aims to understand the function of adding a different proportion of active and inert filler to prepare the mastic and compare their high-temperature rutting and recovery performance. The optimized proportion of active and inert filler was used to prepare the mixture. For high-temperature performance, it is often advised that the F/B ratio not exceed 1.4 (13). The ideal filler content for modified mastic is between 0.8 and 1.2. (14). A F/B ratio of 0.8 was used in this study to prepare all the mastics.

In this study, HL and FA were used as active fillers. HL was used, which enhanced the ductility of asphalt mastic, lowered aging and boosted rutting and moisture resistance (15). Several research efforts had looked at the positive impact of FA on the asphalt mix's ability to resist moisture and rutting and maintain tensile strength (16-17). Due to the considerable rise in mastic consistency, HL and FA fillers must be introduced in small quantities. The performance of an asphalt mixture may be decreased by using too much HL (18). Thus, the proportion of active filler was chosen to be 10% - 30% by the weight of the base binder to prepare the mastics. LS filler was selected for this study because it is a broadly used filler. Along with having a strong stiffening capacity, LS filler also helps the polymer phase function as effectively as possible (4). In a previous study 75% Ba with 5% HL showed better low-temperature cracking performance (19), so, Ba was also selected for this study. The proportion of inert filler was chosen 50% - 70% by the weight of the base binder to prepare the mastics. Various asphalt mineral filler mastics revealed nonlinear rheological behavior at high temperatures (6).

Some studies have been conducted to evaluate the rheological characteristics of asphalt mastic. Dynamic shear rheometer (DSR) was used in these studies following AASHTO T 315 test method. The superpave rutting parameter, often known as the index (G/sinδ), has also been used to measure the flow characteristics of asphalt mastic. But this test method cannot measure mechanical and viscoelastic characteristics of polymer-modified binders and mastics beyond their linear viscoelastic ranges. Also, the Superpave parameter can not measure the energy dissipation of most polymer-modified binder (PMBs) due to delayed elasticity, so a non-reversible cycle loading is suggested (20). Direct measurements of the damage resistance of mastic may be obtained using the MSCR test. Therefore, it is advised that the MSCR test rather than the elastic recovery test be used to assess the recovery property of binders and mastics (21). Typically, rheological parameters like creep recovery performance of viscous materials are measured and evaluated using dynamic shear rheometers (DSRs) by applying a shear force to specimens. (15) following AASHTO T 315 test method. DSR can work in two modes – controlled stress or controlled strain (22-23). The multiple stress creep recovery (MSCR) test method is used during this study, applying a constant stress condition to the sample. To capture the influence of modifiers, MSCR parameters are more efficient than other parameters (24). The MSCR test technique involves loading a sample for one second at constant creep stress and then allowing it to recover for nine seconds at zero stress. The test is performed at two different levels of stress: 0.1 kPa and 3.2 kPa at 64°C (25). The non-recoverable creep compliance (J_{nr}) and MSCR percent recovery (%R) values are computed from the test results at both stress levels, as stated in the applicable AASHTO and ASTM standards (26-27). Instead of using the rutting parameter (G*/sinδ), these two findings from the MSCR test can be utilized to assess rutting potential (28). The J_{nr} and %R is used to construct the polymer method MSCR curve (polymer modification curve) to interpret the elastomeric performance of the aged asphalt mastic and ensure whether the samples are modified with an acceptable range with elastomeric polymer (27).

OBJECTIVES

The main objectives of this study include:

- Evaluate and compare the creep recovery performance of different active, inert, and a combination of active and inert filler in aged asphalt mastic containing modifier and liquid anti-stripping agent based on non-recoverable creep compliance, percent recovery, stress sensitivity, and polymer modification curve.
- Understand the effect of different proportions of active and inert filler in mastic scales by comparing their rheological performance at high temperature and propose an optimum dose.
- Gain a basic understandstanding about the combined effect of fillers, modifiers and anti-stripping agents' dosage on the rheological properties of asphalt mastic

MATERIALS AND METHODS

Materials

Asphalt Binder, Modifier and Anti-stripping Agents

Rutting is a common condition that may be avoided by carefully choosing the binder. Performance Grade PG 58-28 binder is employed in several regions of Newfoundland and Labrador, Canada, particularly in the southern area. Binders are rated according to their performance in extremely cold and hot temperatures. SBS (4% by the weight of base binder) was used in this study as shown in **Fig.-1**. SBS was obtained from local sources. Xiao et al. demonstrated that applying anti-stripping agents may reduce asphalt pavement stripping (29). Adding Zycotherm to the binder enhances the binding between the bitumen and aggregate. Zycotherm makes the aggregate surfaces more hydrophobic (30), eventually improving the contact between the aggregate and binder, thus increasing the performance. Liquid anti-stripping agent Zycotherm shown in **Fig.-1** was added with the modified asphalt to evaluate the creep recovery performance of liquid anti-stripping agents. 0.1% Zycotherm with 4% SBS showing good rutting performance (31). So, 4% SBS and 0.1% Zycotherm have been chosen in this study.

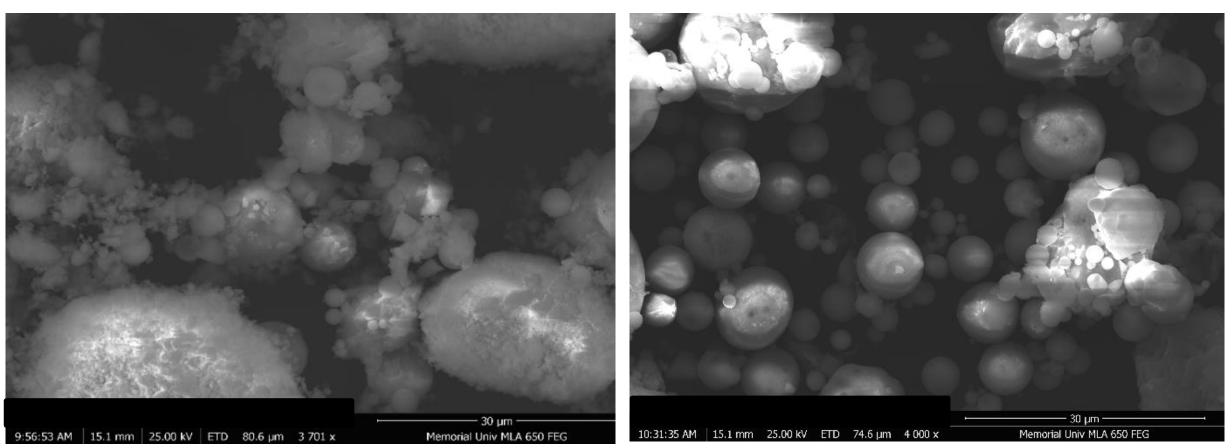
(a) (b)

Fig-1. Binder Modifier (a)SBS and b) Anti-stripping agents Zycotherm

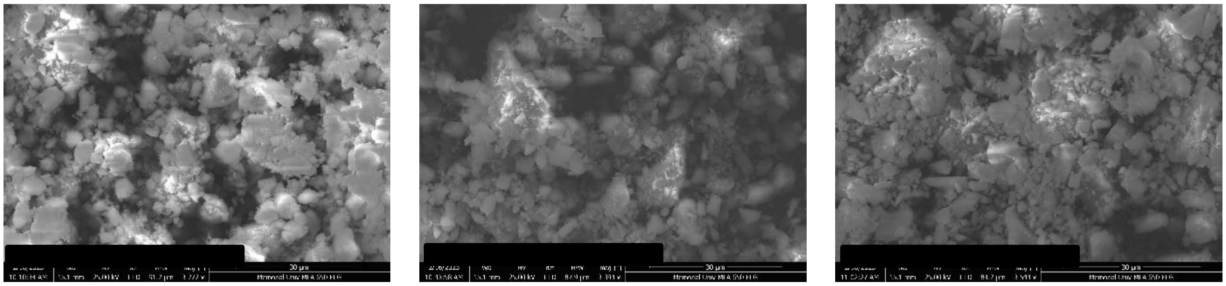
(a) (b)

(c) **(d)** **(e)**

<u>**Fig-2.** Active fillers a) HL, b) FA, and Inert fillers c) LS d) Ba e) DM</u>



(a) (b)



(c) (d) (e)

<u>**Fig-3**.SEM images of Active fillers a) HL, b) FA, and Inert fillers c) LS d) DM e) Ba</u>

Fillers

HL and FA were obtained in powder form, passing sieve No. 200. Conversely, LS, Ba, and DM were obtained from local quarries. Initially, the average size of the collected fillers was between 2-10 mm. To grind the materials, planetary ball mill equipment was used. After grinding the materials, the fine particles of LS, Ba, and DM were sieved with sieve No. 200. The fillers passing sieve No. 200 were collected to use as a filler. The fillers are presented in **Fig.-2**. While preparing, the mastic F/B ratios of 0.8 (80% by the weight of the base binder) were used. To evaluate the creep recovery performance of the asphalt mastic and the mechanical performance of the asphalt mixture, active and inert fillers were mixed so that the F/B ratios remained 0.8. For fabricating the mastics, different proportions (10%,20%,30% by the weight of base binder) of active fillers and different proportions (70%,60%,50% by the weight of base binder) of inert filler materials were mixed, i.e., HL0.1+LS0.7, HL0.2+LS0.6, HL0.3+LS0.5, etc. Some mastics were prepared without mixing any active and inert fillers (80% by the weight of the base binder) to compare the performance of the combination of active and inert fillers, i.e., HL0.8, FA0.8, etc.

As part of this investigation, the physical and chemical characteristics of the fillers were examined to better understand their properties. Specific gravity tests with the pyknometer method, brunauer– emmett–teller (BET) tests for specific surface area (SSA), scanning electron microscopy (SEM) imaging, and X-ray fluorescence spectrometry were used for this characterization. According to SSA and SG tests, Active filler HL has a lower density while Fa has a higher density (**Table 1.**). The SSA of the HL filler was 1.4 times greater than the FA filler. Dolomite filler has the highest density of all the active and inert fillers. Ba has a higher SSA compared to other inert fillers. **Table 1.** shows XRF oxide profiles for chemical analysis. For HL, LS, and DM dominating oxide is CaO, while FA and Ba dominating oxide are SiO_2.

Fig.-3 displays SEM and physical photographs of all the fillers. In the case of HL, most particles are coarser, irregular, and have a porous structure, whereas most FA particles are rounded. For LS filler, most particles have a small grain size while particles of Ba and DM tend to agglomerate. Usually, the particle of Ba is flaky but due to the use of plenary ball mill equipment for grinding, the particle size cannot be properly defined.

Methodology

Modification of Binder

To modify the binder, neat PG 58-28 binder was preheated at 160°C to make it fluid enough. The SBS (4% by weight of base binder) modified binder was collected from a local pavement company. Zycotherm were added with the modified binders separately. A magnetic stirrer was used for 45 minutes at 160°C to prepare the modified PG 58-28 with modifiers and liquid anti-stripping agent. The mixing time and temperature were selected after several trials confirming a homogeneous mixture without any agglomeration.

Preparation of Asphalt Mastic

Prior to blending the fillers with the modified binder, each filler was cleaned and dried for 24 hours at 105°C in the oven. To ensure the homogeneity of the mixture of binder with fillers, the mixing conditions were adjusted for different F/B ratios. To achieve this, each type of filler with different F/B ratios was gradually included into the heated binder, mixing at 160, 170, and 180°C for 60, 120, and 180 minutes, respectively using a magnetic stirrer. The mixing temperature and time was adjusted to avoid the filler sedimentation.

Aging, and Testing

All the binders were heated at 160°C until they became pourable to prepare the sample. Finally, to simulate short-term laboratory aging of the base binders and modified mastics, The Rolling Thin-Film Oven (RTFO) conditioning in accordance with AASHTO T 240 was employed. To prepare the aged mastics, continuous oxidative conditioning was applied at 163°C to the binders for 85 minutes. Finally, the MSCR test protocol was employed using the DSR equipment. A 25mm plate was used to prepare the mastics. In this investigation, 23 asphalt mastics with varying F/B ratios were prepared. All the mastics, including the control binder, were tested twice to ensure the reliability of the data. The experimental plan of the mastic level study is illustrated in **Fig-4**.

Table 1. Oxide composition and physical properties of fillers

	Oxide Composition							**Physical Properties**	
Fillers	MgO	Al_2O_3	SiO_2	CaO	Fe_2O_3	K_2O	Others	SSA (m^2/g)	SG
HL	6.38	0.19	7.42	84.43	0.18	0.67	0.73	10.95	2.23
FA	1.72	26.95	50.69	11.57	5.23	2.77	1.07	7.93	2.35
LS	2.32	1.09	1.75	91.19	1.82	0.97	0.86	4.02	2.74
Ba	8.31	13.61	48.57	12.78	14.76	1.21	0.76	9.31	2.75
DM	14.89	1.78	2.12	80.52	0.11	0.07	0.51	3.89	2.83

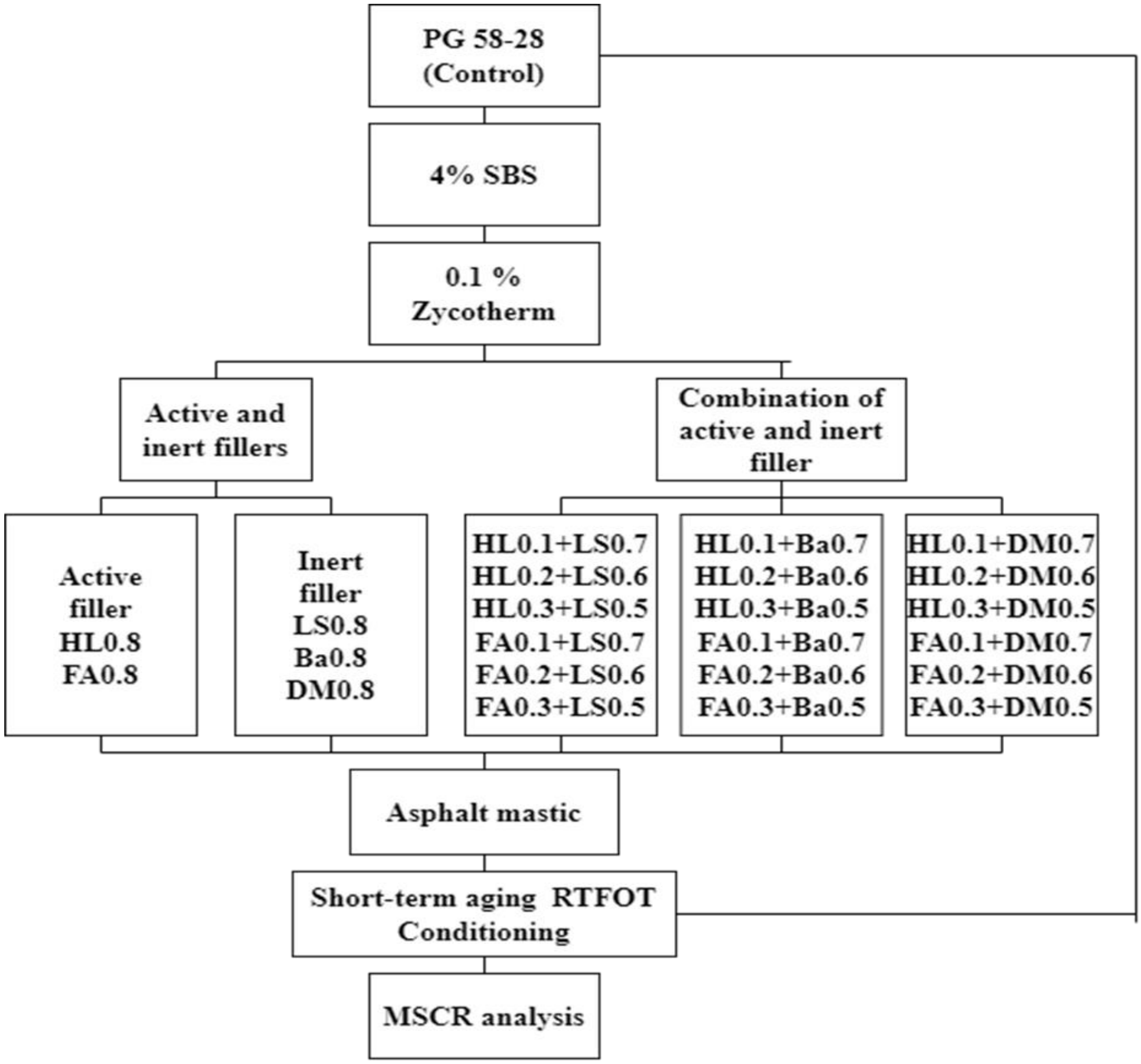


Fig-4. Experiment Design Matrix

Method of Analysis

The multiple stress creep recovery (MSCR) protocol using DSR equipment has been widely accepted to evaluate the permanent deformation behavior of asphalt mastic using the creep-recovery concept (32). Three significant parameters like non-recoverable compliance (J_{nr}), stress sensitivity, and percent recovery are used to identify the creep recovery performance of the asphalt mastic obtained from the MSCR test (33). AASHTO M 332 (34) specifications classify the binders as Extremely Heavy Traffic (E), Very Heavy Traffic (V), Heavy Traffic (H), or Standard Traffic Criteria (S), as based on the J_{nr} value at 3.2 kPa.

Non-recoverable Creep Compliance at 3.2 kPa

The non-recoverable creep compliance (J_{nr}) is calculated to evaluate the deformation as per the AASTHO M 332. The non-recoverable creep compliance, which is evaluated at 3.2 kPa, is used to assess the samples resistance to permanent deformation under repeated loading. A lower value of J_{nr} implies a lower rate of deformation, which implies good elasticity and higher rutting resistance (35). The test temperature was selected at 64° C for MSCR analysis.

Stress Sensitivity

MSCR test allows the assessment of the nonlinearity of asphalt mastic response and identifies the excessive stress sensitivity of samples in the nonlinear range. J_{nr} diff. is the difference between the J_{nr} value at stress levels of 3.2 kPa and 0.1 kPa, as defined in **Equation 1** (36), is utilized as an indicator of stress sensitivity of asphalt mastics. According to AASHTO TP 70, J_{nr} difference should not exceed 75%. If it crosses this limit, then the samples may fail when experiencing higher stress or higher temperature in the real world, which is different from the consideration in the laboratory (34).

$$J_{nr,difference} = \frac{J_{nr,3.2kPa} - J_{nr,0.1kPa}}{J_{nr,0.1kPa}} \times 100\% \tag{1}$$

Where:
(-$J_{nr,difference}$-) is the difference between the J_{nr} value at stress levels of 3.2 kPa and 0.1 kPa;
$J_{nr,3.2kPa}$ is the J_{nr} value at stress levels of 3.2 kPa; and,
$J_{nr,0.1kPa}$ is the J_{nr} value at stress levels of 0.1 kPa.

Modified Method of Stress Sensitivity

Initially, as an indicator of the stress sensitivity of binder's, the percent difference in non-recoverable creep compliance (J_{nr} difference) obtained from the MSCR test is used. It is simply calculated as **Equation 1**. However, the fact that there is no correlation between the % difference and field performance (37). MSCR test is widely used, and many researchers have been concerned about the applicability of this 75% limit (38-39). The percent difference value of a wax-modified binder is more than 75% (38). As a result of the previous approach of stress sensitivity study, this binder should be avoided in road construction since it is very stress sensitive. However, the investigation revealed that the J_{nr} value for a wax-modified binder was very low at 3.2 kPa, implying that this binder was exceptionally rut resistant. As a result, non-recoverable creep compliance and percent difference are incompatible, which is why the previous approach of stress sensitivity was ineffective for modified binders. Stemphihar et al. provided a promising approach for analyzing stress sensitivity (40). This proposed parameter is denoted as the J_{nr} slope. **Equation 2** is used to calculate the stress sensitivity. This newly method does not unfairly penalize modified binder's which have a low J_{nr} value at 3.2 kPa and provides a comparable assessment of stress sensitivity.

$$J_{nr,slope} = \frac{J_{nr,3.2kPa} - J_{nr,0.1kPa}}{3.1} \times 100\% \tag{2}$$

Where:
(-$J_{nr,slope}$-) is the proposed parameter for stress sensitivity;
$J_{nr,3.2kPa}$ is the J_{nr} value at stress levels of 3.2 kPa; and,
$J_{nr,0.1kPa}$ is the J_{nr} value at stress levels of 0.1 kPa.

Percent Recovery at 3.2 kPa

One of the critical parameters influencing the creep recovery performance of mastics in the MSCR test is %R. It is indicative of the ability of an asphalt mastic to restore its deformation after the removal of the creep load. For any asphalt mastic, the value of %R should be non-negative. In other words, the residual strain at the end of the recovery portion should be no more than the accumulated strain at the end of the creep portion for a given creep and recovery cycle. However, Soenen et al. have reported negative %R (41), which is against the physical significance. The negative %R is more common for unmodified samples at 3.2 kPa (42). However, sometimes due to a combination of high temperature, high stress, and low modification level, it can also be observed for modified samples (43). AASHTO M 332 proposed a method to detect the polymer, as shown in **Equation 3**. There is no requirement for J_{nr} values larger than 2 kPa-1 to have a minimum %R value (44-45).

$$\%R = \begin{cases} (29.37)(J_{nr,3.2kPa})^{-0.2633}, & J_{nr,3.2kPa} \geq 0.1 \\ 55, & J_{nr,3.2kPa} < 0.1 \end{cases} \quad (3)$$

Where:
(-%R-) is the Percent Recovery;
$J_{nr,3.2kPa}$ is the J_{nr} value at stress levels of 3.2 kPa;

RESULTS AND DISCUSSIONS

Non-Recoverable Creep Compliance, Jnr

Analysis of Jnr of Asphalt Mastics Contain HL and other Inert Fillers

From **Fig.-5**, all the mastics contained different filler or combination of active and inert filler had a lower J_{nr} value compared to the neat aged binder. J_{nr} value for neat aged PG 58-28 was 2.15 kPa^{-1}. All the mastics had a J_{nr} value less than 0.14 kPa^{-1}. From the binder level analysis, without the inclusion of any filler J_{nr} value of SBS-modified 0.1% Zycotherm was found to be 0.2 kPa^{-1} (46). Inclusion of filler thus lower the Jnr value and improved the rutting performance. Combination of active filler HL and inert filler LS had a lower value of J_{nr} compared to other mastics. This observation could be explained by the combined well graded particle size distribution of HL and LS. HL has a porous structure while LS a structure with very fine particles Mastic prepared with 10% (by the weight of base binder) HLand 70 % (by the weight of base binder) LS had the lowest value of J_{nr} and thus showed better resistance to permanent deformation. With the increase in HL and decrees of LS, the J_{nr} value was increasing. This might be due to the higher absorption capacity of HL. The same pattern could be seen for the HL with Ba and HL with DM.

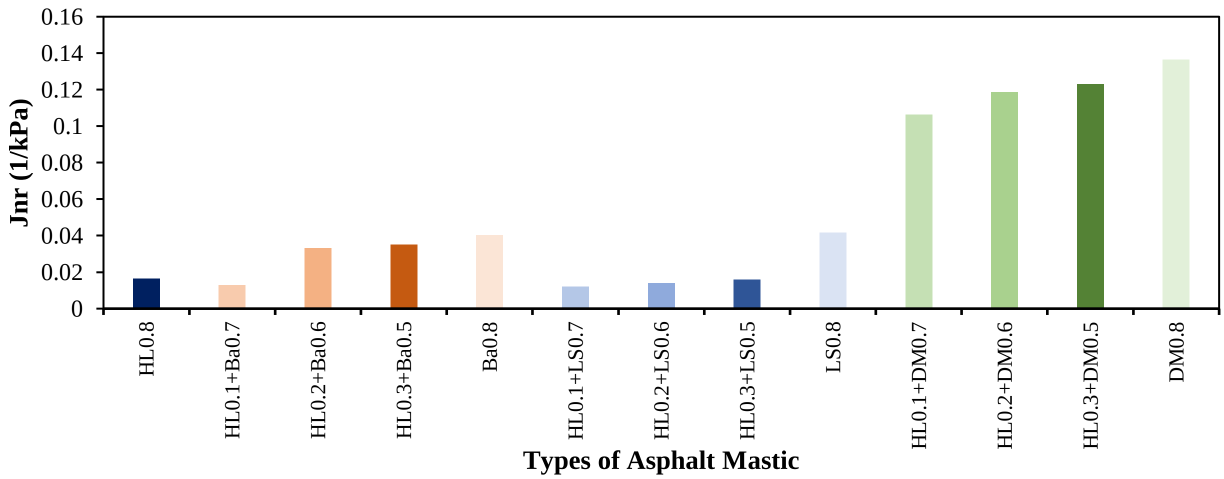


Fig-5. Comparison of J_{nr} at 3.2 kPa^{-1} of Asphalt Mastics contain HL and other inert fillers

10% (by the weight of base binder) HLand 70 % (by the weight of base binder) Ba has lower J_{nr} value than HL0.8 whereas other dosage of HL and Ba has a higher J_{nr} value than HL 0.8. All the mastics of HL+DM has higher J_{nr} value compared to other mastics. Thus, the combination of HL and DM show poor rutting performance.

Analysis of Jnr of Asphalt Mastics Contain FA and other Inert Fillers

According to **Fig.-6**, the J_{nr} values were ranging from 0.04-0.14 kPa^{-1} for FA asphalt mastic whereas the J_{nr} values for HL mastics ranged from 0.012-0.13 kPa^{-1}. So, as expected inclusion of fillers with binder had lower J_{nr} values than the neat aged binder which implied better rutting resistance. Most of the mastics prepared with the combination of active filler (FA) and other inert filler (LS, Ba, DM) had a J_{nr} value lower than the mastic prepared with only inert filler LS and Ba. Mastic prepared with 30% (by the weight of base binder) FA and 50 % (by the weight of base binder) LS had the lowest value of J_{nr} than other mastics. With the increase in FA and decrees of LS, the J_{nr} value was decreasing. Same pattern could be seen for mastics with FA+Ba and FA+DM. This was due to the addition of FA improved the rutting performance of mastics (16).

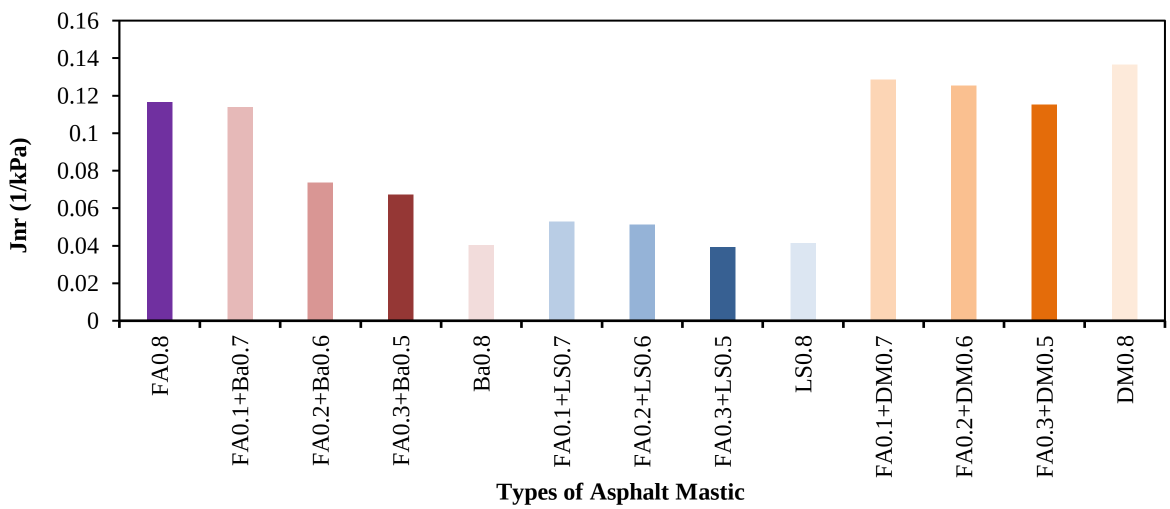


Fig-6. Comparison of Jnr at 3.2 kPa^{-1} of Asphalt Mastics contain FA and other inert fillers

All the mastics met the extremely heavy traffic criteria based on AASHTO M 332 specification. Overall, SBS and 0.1% Zycotherm modified mastics prepared with active filler (HL, FA) and inert filler LS had a lower range of Jnr value which implied better rutting performance.

Stress Sensitivity

Analysis of Stress Sensitivity of Asphalt Mastics Contain HL and other Inert Fillers

Fig.-7 compares the stress sensitivity of all the asphalt mastic with different proportion of HL and other inert filler. All the mastics were more stress sensitive than the neat aged binder according to the previous method of stress sensitivity. All the HL+Ba and HL+LS mastics passed the stress sensitivity criteria. However, all the HL+DM failed the stress-sensitive criteria, which suggested that high temperatures or heavy loads excessively stress these mastics. Some mastics contain only active (HL) or inert filler (Ba) passed the stress sensitivity criteria. Combination of 10% HLand 70 %) LS had the lowest stress sensitivity compared to the other mastics.

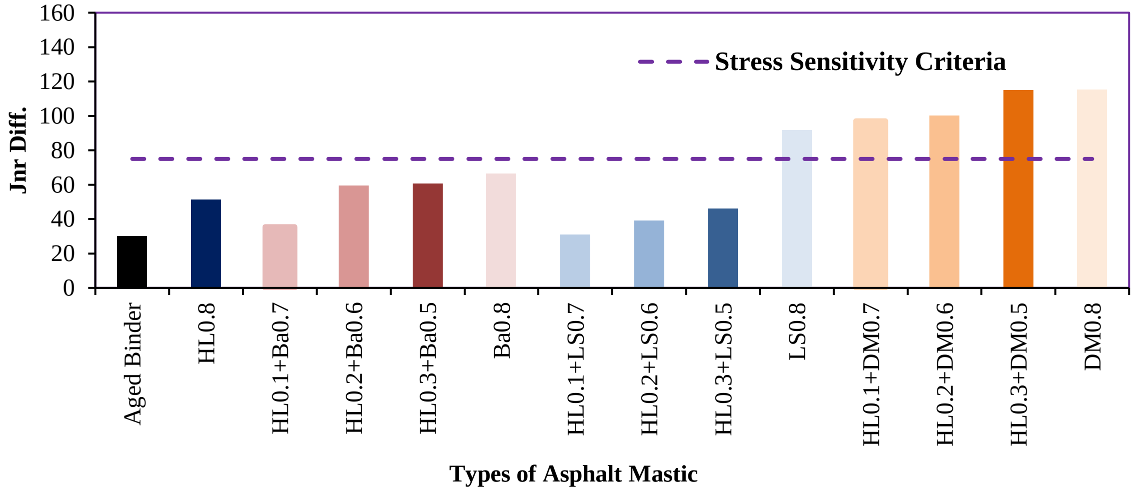


Fig-7. Comparison of Stress Sensitivity of Asphalt Mastics contain HL and other inert fillers

Analysis of Stress Sensitivity of Asphalt Mastics Contain FA and other Inert Fillers

Fig.-8 compares the stress sensitivity of all the asphalt mastic with different proportion of FA and other inert filler. FA mastics were more stress sensitive than HL mastics. This could be explained by the higher J_{nr} value of FA mastics compared to HL mastics. All the FA+Ba mastics failed the stress sensitivity criteria whereas all HL+Ba passed the stress sensitivity criteria. all the FA+DM , revealing that high temperatures or large loads severely stress these binders since they failed the stress sensitivity criteria. The stress sensitivity criteria were met by all other mastics containing FA+LS. Combination of 30% FA and 50 % LS had the lowest stress sensitivity compared to the other mastics.

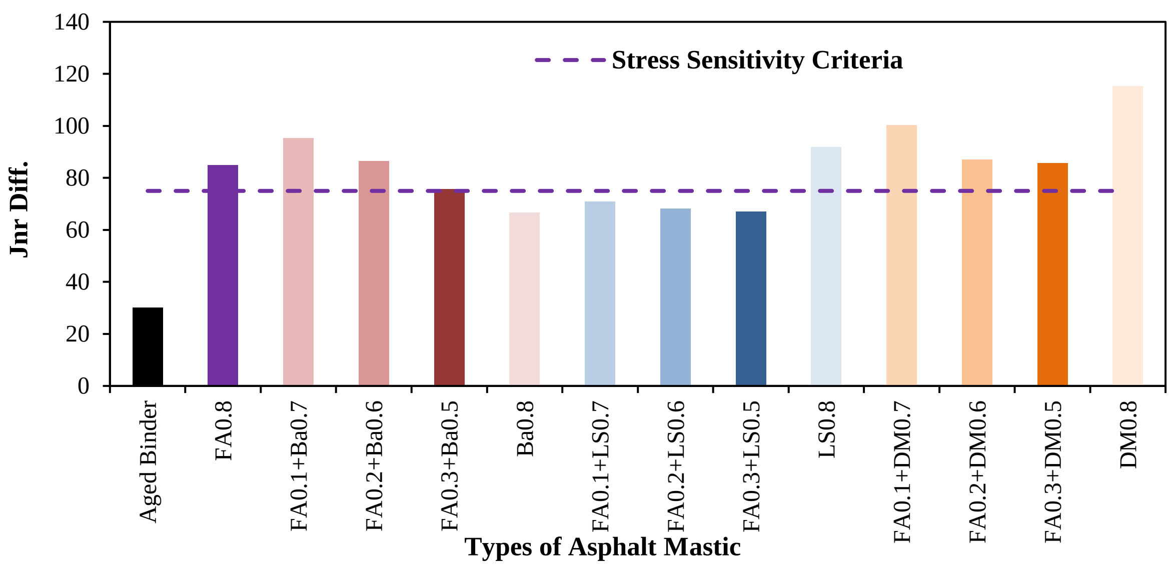


Fig-8. Comparison of Stress Sensitivity of Asphalt Mastics contain HL and other inert fillers.

Modified Stress Sensitivity

Analysis of Modified Stress Sensitivity of Asphalt Mastics Contain HL and other Inert Fillers

The comparison of the modified stress sensitivity asphalt mastic with varying proportions of HL other inert filler is shown in **Fig.-9**. All the mastics passed the modified stress sensitivity criteria, whereas LS0.8, DM0.8 and all the HL+DM failed to pass the previous stress sensitivity criteria. The newly proposed stress sensitivity technique indicated that all HL+LS mastics, HL0.8 and HL0.1+Ba0.7 had a lower stress sensitivity than the neat aged binder. All HL mastics containing Zycotherm were less stress sensitive than other mastics. Like the previous method, combination of 10% HLand 70 %) LS had the lowest stress sensitivity compared to the other mastics.

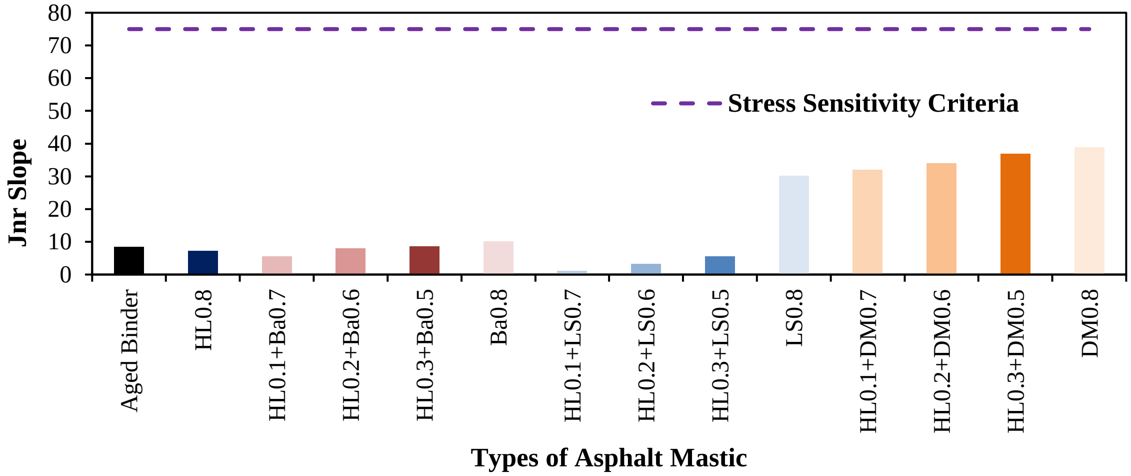


Fig-9. Comparison of Modified Stress Sensitivity of Asphalt Mastics contain HL and other inert fillers

Analysis of Modified Stress Sensitivity of Asphalt Mastics Contain FA and other Inert Fillers

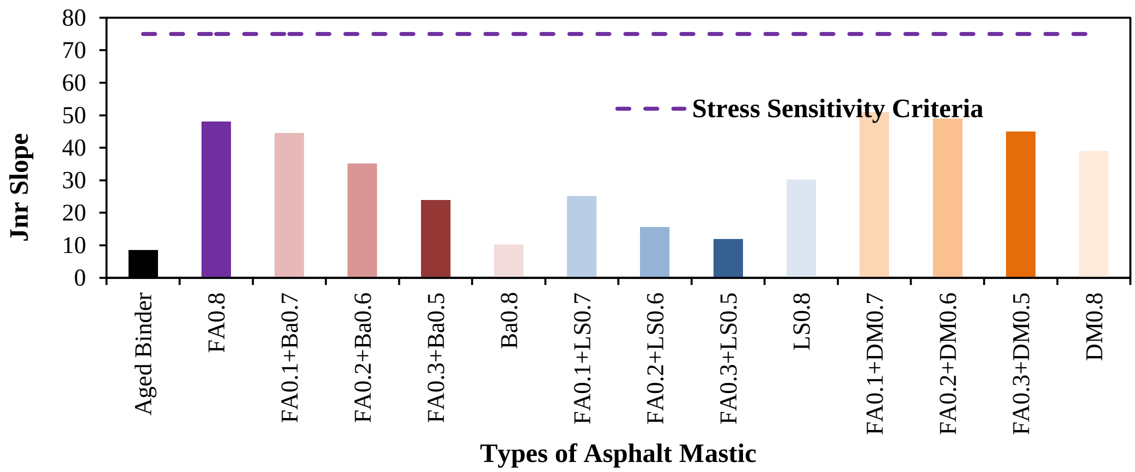


Fig-10. Comparison of Modified Stress Sensitivity of Asphalt Mastics contain FA and other inert fillers

Fig-10 illustrates a comparison of the asphalt mastic with different proportion of FA and other inert filler. All the mastics passed the modified stress sensitivity criteria, whereas most mastics failed to pass the previous stress sensitivity criteria. All mastics had higher stress sensitivity than the aged binder, according to the modified method of stress sensitivity analysis.

Polymer Method and MSCR Grade

Analysis of Polymer Method of Asphalt Mastics Contain HL and other Inert Fillers

Polymer modification curves of asphalt mastic with different proportion of HL and other inert filler are shown in **Fig.-11**.

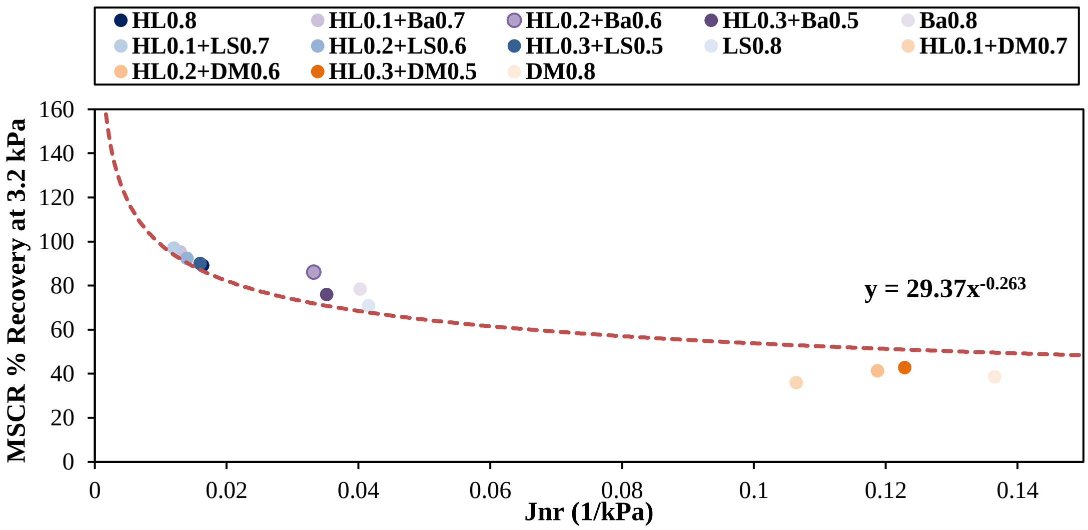


Fig-11. Polymer Method MSCR curve of Asphalt Mastics contain HL and other inert fillers

Addition of fillers enhanced the elastic behavior of the mastics. Most of the asphalt mastics (9 out of 13) passed the polymer modification criteria and clustered above the line. According to asphalt institute guidelines, the modification was done within an acceptable range for these mastics, and these mastics showed an excellent recovery performance. All the HL+LS and HL+Ba showed an excellent recovery. All the HL+DM failed to pass the polymer modification criteria and clustered under the line and showed poor recovery performance. This implied that the modification was not done within an acceptable range. Combination of 10% HLand 70 % LS had the highest %R compared to the other mastics., thus excelling in elastic recovery. All the mastics could be graded according to MSCR grading as the Jnr value was less than 4.5 kPa-1.

Analysis of Polymer method of Asphalt Mastics Contain FA and other Inert Fillers

Fig.-12 displays the polymer modification curves for asphalt mastic with different proportion of FA and other inert filler. All the proportions of FA+LS and FA+BA passed the polymer modification criterion and clustered over the line. Therefore, the modification was carried out within a range suitable for these mastics, and they exhibited outstanding recovery capabilities. However, all the FA+DM congregated beneath the line and performed poorly after recovery. This suggested that the modification was not made within an acceptable range. Given that the J_{nr} value was less than 4.5 kPa^{-1}, all the mastics of FA and other inert filler may be graded according to MSCR grading**.** Combination of 30% FA and 50 % LS had the highest %R compared to the other mastics**.** A summary of all the performance parameters considered for this study is given below in **(Table 2).**

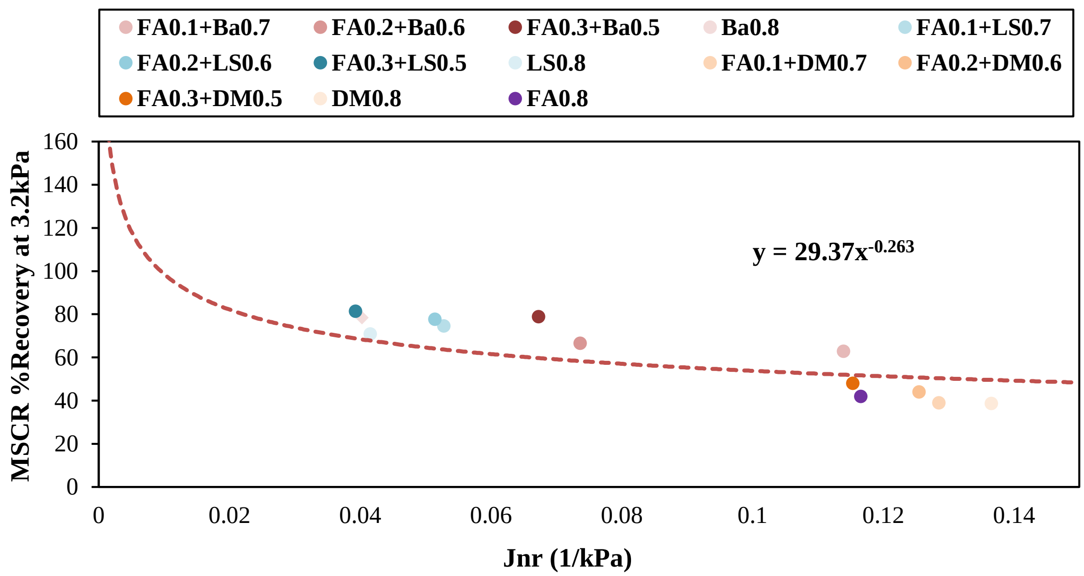


Fig-12. Polymer Modification curve of Asphalt Mastics contain FA and other inert fillers

Table 2. Summary of MSCR Test Parameters

No	Anti-stripping Agent	Active Filler	Inert Filler	Modifier	Meet Stress Sensitivity Criteria	Meet Modified Stress Sensitivity	%Recovery (Meets AASTHO T 350)	MSCR GRADE AASHTO M 332
1	Zycotherm 0.1%	HL0.8	N/A	SBS 4%	Yes	Yes	Yes	PG 58E-28
2	Zycotherm 0.1%	HL0.1	LS0.7	SBS 4%	Yes	Yes	Yes	PG 58E-28
3	Zycotherm 0.1%	HL0.2	LS0.6	SBS 4%	Yes	Yes	Yes	PG 58E-28
4	Zycotherm 0.1%	HL0.3	LS0.5	SBS 4%	Yes	Yes	Yes	PG 58E-28
5	Zycotherm 0.1%	N/A	LS0.8	SBS 4%	No	Yes	Yes	PG 58E-28
6	Zycotherm 0.1%	HL0.1	Ba0.7	SBS 4%	Yes	Yes	Yes	PG 58E-28
7	Zycotherm 0.1%	HL0.2	Ba0.6	SBS 4%	Yes	Yes	Yes	PG 58E-28
8	Zycotherm 0.1%	HL0.3	Ba0.5	SBS 4%	Yes	Yes	Yes	PG 58E-28
9	Zycotherm 0.1%	N/A	Ba0.8	SBS 4%	Yes	Yes	Yes	PG 58E-28
10	Zycotherm 0.1%	HL0.1	DM0.7	SBS 4%	No	Yes	No	PG 58E-28
11	Zycotherm 0.1%	HL0.2	DM0.6	SBS 4%	No	Yes	No	PG 58E-28
12	Zycotherm 0.1%	HL0.3	DM0.5	SBS 4%	No	Yes	No	PG 58E-28
13	Zycotherm 0.1%	N/A	DM0.8	SBS 4%	No	Yes	No	PG 58E-28

14	Zycotherm 0.1%	FA0.8	N/A	SBS 4%	No	Yes	No	PG 58E-28
15	Zycotherm 0.1%	FA0.1	LS0.7	SBS 4%	Yes	Yes	Yes	PG 58E-28
16	Zycotherm 0.1%	FA0.2	LS0.6	SBS 4%	Yes	Yes	Yes	PG 58E-28
17	Zycotherm 0.1%	FA0.3	LS0.5	SBS 4%	Yes	Yes	Yes	PG 58E-28
18	Zycotherm 0.1%	FA0.1	Ba0.7	SBS 4%	No	Yes	Yes	PG 58E-28
19	Zycotherm 0.1%	FA0.2	Ba0.6	SBS 4%	No	Yes	Yes	PG 58E-28
20	Zycotherm 0.1%	FA0.3	Ba0.5	SBS 4%	No	Yes	Yes	PG 58E-28
21	Zycotherm 0.1%	FA0.1	DM0.7	SBS 4%	No	Yes	No	PG 58E-28
22	Zycotherm 0.1%	FA0.2	DM0.6	SBS 4%	No	Yes	No	PG 58E-28
23	Zycotherm 0.1%	FA0.3	DM0.5	SBS 4%	No	Yes	No	PG 58E-28

CONCLUSIONS

The following conclusions can be drawn based on the experimental results collected from the mastic and mixture level analysis of different parameters.

- A combination of active filler HL and inert filler LS improved the mastics' rutting resistance compared to those prepared with only active or inert filler by decreasing the J_{nr} value.10% HL+70% LS had a lower J_{nr} value than other mastics. Whereas, for the mastics prepared with the combination of FA and other inert fillers, only 30%Fa+50%LS showed better performance than that prepared with only inert filler Ba..
- The modified method of stress sensitivity analysis showed that all the mastic passed the stress sensitivity criteria, which implied these binders can perform well in high temperatures or heavy loads. However, some mastics failed the previous method of stress sensitivity. All the mastics prepared with the combination of HL+LS and HL+Ba had less stress sensitivity than the aged binder, according to the modified method of stress sensitivity.
- From the polymer modification curve, all the mastics can be graded according to MSCR grading as the J_{nr} value is less than 4.5 kPa-1 for all the mastics. In the case of elastomeric performance, the mastics prepared with the combination of HL and other inert fillers (LS, Ba, DM) outperformed the mastics prepared with the combination of FA and other inert fillers. 10% HL+70% LS had better recovery performance compared to the other mastics.

RESEARCH APPLICATION AND RECOMMENDATION

This study used SBS and Zycotherm to modify the binder, Two active fillers (HL and FA) and three inert fillers (LS, Ba, DM) were combined separately in three different proportions and mixed with the modified binder to fabricate the mastics. RTFO conditioning was employed to evaluate these short-term aged asphalt mastics' creep recovery performance in mastic levels. The combination of active filler HL(10%) and inert filler LS(70%) performed better than other mastics. This mastic passed Extremely Heavy traffic loading criteria based on AASHTO M 332, modified stress sensitivity criteria, and polymer modification curve. So, this mastic(10%HL+70%LS) is suggested to use in the asphalt mixture instead of using only active, inert, or other combinations of fillers to prepare the mastics to minimize the moisture susceptibility and to strengthen the adhesion of binder with aggregate. The performance of the mastics depends on the mixing procedure. A mechanical or electrical mixer would produce a more homogenous mixture than a magnetic stirrer. Long-term aging, the low-temperature performance of the mixtures, and the chemical characterization of these mastics can also be considered for future analysis. The chemical interaction of active and inert filler in mastic scales and mixture levels can also be evaluated.The following summarizes the application of this experimental work and recommendations for future study.

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REFERENCES

1. Yildirim, Y. Polymer Modified Binders. Construction and Building Materials, Vol. 21, 2007,pp. 66–72. https://doi.org/10.1016/j.conbuildmat.2005.07.007
2. Airey, G. D. Rheological Evaluation of Ethylene Vinyl Acetate Polymer Modified Binders. Construction and Building Materials, Vol. 16, 2002, pp. 473–487.
3. Little, D.N. and D.R. Jones, Chemical and Mechanical Processes of Moisture Damage in Hot-Mix Asphalt Pavements. Moisture Sensitivity of Asphalt Pavements. *National Seminar, Transportation Research Board*, San Diego, California, 2003, pp. 37–70.
4. Rieksts, K., M. Pettinari, and V. Haritonovs. The influence of filler type and gradation on the rheological performance of mastics. Road Materials and Pavement Design. Vol 20, No 4, 2019 pp 964–978, https://doi.org/10.1080/14680629.2018.1428216.
5. Huang, B., X. Shu, and X. Chen, Effects of mineral fillers on hot-mix asphalt laboratory-measured properties. I*nternational Journal of Pavement Engineering*. Vol. 8, No 1, 2007, pp 1–9, https://doi.org/10.1080/10298430600819170.
6. Taylor, R., and G. D. Airey. Influence of surface interactions between binder and mineral fillers on the rheology of binder-filler mastics. Efficient Transportation and Pavement Systems: Characterization, Mechanisms, Simulation, and Modeling. Proceedings of the 4th International Gulf Conference on Roads, 2W008, pp 453–464.
7 Roman, C, and Garcıa-Morales, M., Linear rheology of bituminous mastics modified with various polyolefins: a comparative study with their source binders, *Materials Structure* Vol 50 (1), 2016 pp 86-94.
8 Yi-qiu, T., Z. -H. Li, X.-Y. Zhang, and Z.-J. Dong. Research on high- and lowtemperature properties of asphalt-mineral filler mastic. *Journal of Materials in Civil Engineering*, Vol 22, 2010, pp 811–819
9 Kuity, A., S. Jayaprakasan, and A. Das, Laboratory investigation on volume proportioning scheme of mineral fillers in asphalt mixture,*Construction and Building Materials*, Vol. 68, 2014, pp 637–643.
10 Moraes, R. and H. Bahia. Effect of mineral fillers on the oxidative aging of binders, Transportation Research. Record: Journal of the Transportation Research Board, Vol.

2506, 2015, pp. 19–31. https://doi.org/10.3141/ 2506-03.
11 Kim, Y.-R ., and D.N. Little. Linear viscoelastic analysis of asphalt mastics, *Journal of Materials in Civil Engineering*, Vol. 16, No 2, 2004, pp 122-132, https://doi.org/10.1061/(asce)0899-1561.
12. Antunes, V., A. C. Freire, L. Quaresma, and R. Micaelo. Influence of the geometrical and physical properties of filler in the filler–binder interaction. Construction and Building Materials, Vol 76, 2015,pp 322-329. https://doi.org/10.1016/j.conbuildmat.2014.12.008.
13 Zhang, Z.Q., Zhang, W.P., and Li, P. Ratio of filler bitumen of asphalt mixture. *Journal of Changan University,* Vol. 24 (5), 2004, pp 7-10
14 Qiu, H. Influence of filler–bitumen ratio on performance of modified asphalt mortar by additive.5Journal of Modern Transportation, 21 (1), 2013, pp 40–46.
15 Bai, F., X. Yang, and G. Zeng. Creep and recovery behavior characterization of asphalt mixture in compression. *Construction and Building Materials*, Vol. 54, 2014, pp 5104–5118.
16 Asi, I., and Assaad, A.Effect of Jordanian oil shale fly ash on asphalt mixes. *Journal of Materials in Civil Engineering,* Vol.17(5), 2005,pp 553–559.
17 Xiao, F., Shivaprasad, P., & Amirkhanian, S Low-volume road wma mixtures: Moisture susceptibility of mixtures containing coal ash and roofing shingle with moist aggregate. Journal of Materials in Civil Engineering, Vol.24(1), 2012.pp 48–56.
18 Zhou, L., and Sun Y. Determination of HL Content Based on Asphalt Mastic High Temperature Performances. International Academic Exchange Conference on Science and Technology Exchange Conference on Science and Technology Innovation 2019.
19 Das, A.K., and Shing, D. Investigation of rutting, fracture and thermal cracking behavior of asphalt mastic containing basalt and hydrated lime fillers. *Construction and Building Materials.* Vol. 141, 2017, pp 442-452
20 Delgadillo R, Nam K, Bahia H “Why do we Need to Change G*/sind and how? *Road Materials and Pavement Design*, Vol. 7(1): 2006, pp 7–27.
21 Clopotel, C.S., and Bahia, H.U,. Importance of elastic recovery in the dsr for binders and mastics. *Engineering Journal*, Vol. 16 (4), 2012.pp 99–106.
22 Hafeez, I.,and M. A. Kamal. Creep compliance: A parameter to predict rut performance of binders and mixtures. *Arabian Journal for Science and Engineering*, Vol. 39, No 8, 2014,pp 5971-5978.
23 Shenoy, A. Non-recovered compliance from dynamic oscillatory test vis-à-vis non-recovered compliance from multiple stress creep recovery test in the dynamic shear rheometer. *International Journal of Pavement Engineering*, Vol. 9, No 5, 2008, pp 329–341.
24 Ahmed R. Bin, K, Hossain, M, Aurilio, and R.M. Hajj. Effect of Rejuvenator Type and Dosage on Rheological Properties of Short-Term Aged Binders. *Materials and Structures*, Vol. 54, No 3,2021
25 Hossain, Z., et al.,. Use of the multiple stress creep recovery (mscr) test method to characterize polymer-modified asphalt binders.*Journal of Testing and Evaluation*, Vol.44 (1), 2016. pp 507–520.
26 *Standard Method of Test for Multiple Stress Creep Recovery (MSCR) Test of Binder Using a Dynamic Shear Rheometer (DSR)*. AASHTO TP 70, 2009.
27 *Standard Test Method for Multiple Stress Creep and Recovery (MSCR) of Binder Using a Dynamic Shear Rheometer*. ASTM) D 7405, 2010.
28 Smucker, B., Krzywinski, M., & Altman, N.. Two-level factorial experiments. *Nature Methods*, Vol *16*(3), 2019,pp 211–212
29 Xiao, F., W. Zhao, T. Gandhi, S. N. Amirkhanian, and M. Asce. Influence of Antistripping Additives on Moisture Susceptibility of Warm Mix Asphalt Mixtures. *Journal of Materials in Civil Engineering*, Vol. 22, No. 10, 2010, pp. 1047–1055.

https://doi.org/10.1061/ASCEMT.1943-5533.0000111.
30 Mirzaiyan, D., M. Ameri, A. Amini, M. Sabouri, and A. Norouzi. Evaluation of the Performance and Temperature Susceptibility of Gilsonite-and SBS-Modified Binders. Construction and Building Materials, Vol. 207, 2019, pp 679-692. https://doi.org/10.1016/j.conbuildmat.2019.02.145
31 Islam, T., M. Aurilio, K. Hossain, C. Bazan and G. Caul. Evaluation of Rheological Properties of SBS and Gilsonite Modified Binders Containing Liquid Anti-Stripping Additives. Presented at 101st Annual Meeting of the Transportation Research Board (TRB) , Washington DC, USA,2022.
32 Singh, D., and A. V. Kataware. Comparison of Different Rheological Parameters for Rutting Susceptibility of SBS + WMA Modified Binders. *Innovative Infrastructure Solutions*, Vol. 1, No. 28, 2016, pp. 1–10. https://doi.org/10.1007/s41062-016-0026-7.
33 Golalipour A, H.U. Bahia and H.A. Tabatabaee. Critical Considerations Toward Better Implementation of the Multiple Stress Creep and Recovery Test. *Journal of Materials in Civil Engineering,* Vol. 29, No 5, 2016, 04016295.
34 *Standard Specification for Performance-Graded Using Multiple Stress Creep Recovery (MSCR) Test*. AASHTO M 332-14, 2014.
35 Wasage, T.L.J., J. Stastna, and L. Zanzotto. Rheological Analysis of Multi-Stress Creep Recovery (MSCR) Test. *International Journal of Pavement Engineering,* VOL. 12, No 6, 2011, pp 561–568.
36 *Standard Method of Test for Multiple Stress Creep Recovery (MSCR) Test of Binder Using a Dynamic Shear Rheometer (DSR)*, AASHTO) T 350–14, 2014.
37 Gaspar M.S., B. Nogueira, K.L. Vasconcelos, L.F. Leite, and L.L. Bernucci. Effect of Different Creep and Recovery Times on the MSCR Test for Highly Modified Binder. *Journal of Testing and Evaluation*, Vol 49, 2019.
38 Laukkanen O, H. Soenen, T. Pellinen, S. Heyrman, and G. Lemoine. Creep-Recovery Behavior of Bituminous Binders and its Relation to Asphalt Mixture Rutting. *Material Structure*, Vol. 48,No 12, 2015, pp 4039–4053.
39 Behnood A, and J. Olek. Stress-Dependent Behavior and Rutting Resistance of Modified Binders: An MSCR Approach. *Construction. and Building Materials*. Vol 157, 2017, pp 635–646..
40 Stempihar J, A. Gundla, and B.S.Underwood, "Interpreting Stress Sensitivity in the Multiple Stress Creep and Recovery Test, *Journal of Materials in Civil Engineering* Vol. 30 No 2, 2018, 04017283.
41 Soenen H, T. Blomberg, T .Pellinen, and O. Laukkanen. The Multiple Stress Creep-Recovery Test: A Detailed Analysis of Repeatability and Reproducibility. *Road Materials and Pavement Design*. Vol. 14 (sup1), 2013, pp 2–11.
42 Saboo N, and P. Kumar. A Study on Creep and Recovery Behavior of Binders. *Construction and Building Materials* Vol. 96, 2015, pp 632–640.
43 Jafari M, and A. Babazadeh. Evaluation of Polyphosphoric Acid Modified Binders Using Multiple Stress Creep and Recovery and Linear Amplitude Sweep Test. *Road Materials and Pavement Design*, Vol. 17, No 4, 2016, pp 859–876.
44 Anderson, M. Evaluation of DSR Creep-Recovery Testing as a Replacement for PG Plus Tests. *Asphalt Institute (AI), Association of Modified Asphalt Producers (AMAP) Annual Meeting,* Boston, MA, 2007.
45 Anderson M. "Understanding and Implementing the Multiple Stress Creep Recovery (MSCR) Test and Specification", *Association of Modified Asphalt Producers Annual Meeting, Savannah, GA* 2010. 54
46 Feroz, S.I., Islam, T.,Hossain, K.,Ahmed, R.B.,and Bazan, C. Effect of Rejuvenators and Anti-Stripping Agents on Creep Recovery Performance of Modified Aged Binder. Presented at 67th Annual Conference Canadian Technical Asphalt Association (CTAA),

Kelowna, BC, Canada. 2022.