Enhancing Performance Graded Specification of Asphalt Binder for More Sustainable Pavement in Singapore

Aye Nandar Win Maung*, Tiah Guo Wei, Lee Yang Pin Kelvin and Ho Nyok Yong

Samwoh Innovation Centre Pte Ltd, 12 Kranji Way, Singapore 739454
*aye.maung@samwoh.com.sg

Abstract. Polymer modified binder (PMB) is used in Singapore and the surrounding region for purpose of enhancing the durability and strength in asphalt pavements, particularly with high traffic volumes and heavy traffic loads. The selection of an appropriate PMB is crucial, as its properties significantly depend on the type of modifiers, content percent, and binder-modifiers compatibility. The Superpave Performance Graded (PG) specification was developed in the 1990s to characterize the properties and performance of asphalt binders. In Singapore, the PG specification has been used to specify the properties of PMBs used in asphalt pavements for highways and airport pavements. The local specification focuses mainly on the performance at high temperature mainly rutting resistance due to the hot climate conditions. However, binder's rutting factor (G*/sin δ) by the Superpave PG specification does not correlate well to the asphalt mixture's rutting based on research studies. To address the issue, the multiple-stress creep and recovery (MSCR) test was introduced as improvement to the Performance Graded specification. The current study aims to evaluate the performance of different modified binders using the Superpave PG specification as well as MSCR tests. Five types of PG 82 binders were tested which include four PMBs from different suppliers and one recycled plastic (RP) modified binder. The results showed that the PG 82 binders showed significantly different performance when tested using the MSCR test. The study also demonstrated that the MSCR test can provide more accurate assessment of the modified binders and will provide a more durable and sustainable asphalt pavement if included in the current binder specification.

Keywords: Superpave Performance Graded (PG) Specification, Non-recoverable creep compliance J_{nr}, Percent Recovery R, Fatigue Performance

1 Introduction

Sustainable infrastructure development is demanded across the world with innovative materials to amplify the performance and durability of road construction. Polymer modified binder (PMB) is widely used in asphalt pavement since many years ago as it provides better durability than conventional non-modified binder. With the increase in traffic loads and environmental temperature over the years, performance grade of PMBs are increasing along with the rise in maximum pavement temperature. In Singapore,

X. Qu et al. (eds.), *Proceedings of the 14th Asia-Pacific Conference on Transportation and the Environment (APTE 2025)*, Atlantis Highlights in Engineering 41,
https://doi.org/10.2991/978-94-6463-972-8_8

PMBs with high temperature grade as high as PG 82 has been used due to the hot climate conditions. A typical PG 82 binder specification is shown in Figure 1 which focuses mainly on the high temperature performance.

Property	Requirement	Test Method
Fresh Material High Temperature Performance Grade (PG)	PG 82	AASHTO M 320
Softening Point, ℃ (minimum)	65	ASTM D 36
Viscosity at 135 ℃, Pa-s (maximum)	3	ASTM D 4402
Flash Point, ℃ (minimum)	230	ASTM D 92
Elastic Recovery of Asphalt Binder at 25 ℃ , 10cm elongation, % (minimum)	70	ASTM D 6084
Dynamic Shear, G*/sin δ, tested at 82 ℃ @ 10 rad/s, kPa (minimum)	1.0	AASHTO TP 5
After Rolling Thin Film Oven Test (RTFOT) Mass Loss, % (minimum)	1.0	ASTM D 2872
Dynamic Shear, G*/sin, tested at 82 ℃ @ 10 rad/s, kPa (minimum)	2.2	AASHTO TP 5
After Storage, 72 Hours at 180 ℃ Difference (softening point top of sample minus softening point bottom of sample), ℃ (minimum)	5	-

Fig. 1. Typical PG 82 Specification for PMB in Singapore

The rutting resistance property of a binder can be evaluated by Dynamic Shear Rheometer (DSR) testing parameter: the complex shear modulus G* and phase angle δ. Additional test such as elastic recovery was specified to ensure the modified binders are modified with elastomeric polymers. However, the rutting parameter, G*/sin δ, exhibited poor correlation with asphalt mixture rutting according to past studies [2,3]. The latest Multiple Stress Creep and Recovery (MSCR) test provides a new high temperature binder specification with precise rutting performance of the asphalt binder which is documented in AASHTO M332 [4]. The MSCR test measures the rutting parameter J_{nr} (non-recoverable compliance) and elastic response %R (percent recovery) in modified binder. The J_{nr} characterized the binder at strain levels which exceed the linear viscoelastic limit and generates requisite deformation to measure the benefits of modified asphalt binder [5,6]. Studies have proved that Jnr has well correlated with asphalt mixture rutting when compared to Superpave rutting parameter G*/sin δ [7,8].

This study aims to evaluate the benefit of including MSCR test in characterizing modified binders in Singapore. The study includes polymer modified binders with SBS (styrene-butadiene-styrene) as well as recycled plastic (RP). The latter has shown to improve asphalt rutting performance, and thereby provides environmental benefits by increasing plastic recycling rate and contribute to environmental sustainability [9].

2 Methodology

2.1 Binder Testing

Four SBS polymer modified binders (PMBs) and one recycled-plastics (RP) modified binder samples of PG 82 grade were tested based on the PG and local specification requirements. The tests included dynamic shear, rotational viscosity, softening point temperature and elastic recovery. To simulate the binder ageing in asphalt mixture mixing process, modified binders were conditioned at 163°C in Rolling Thin Film Oven for85 minutes. Resistance to shear deformation after ageing was determined by DSR at 82°C.

The MSCR test was conducted on RTFO aged modified bitumen samples at specified temperature and two stress levels 0.1kPa and 3.2kPa. MSCR test determine the elastic response and how it changes under certain stress in modified bitumen. Non-recoverable creep compliance J_{nr} at 3.2kPa (hereinafter denoted as $J_{nr3.2}$) indicates the endurance to permanent deformation of bitumen under repeated loading state, thus lower $J_{nr3.2}$ represents better rutting resistance [7]. Apart from MSCR, modified binders were conditioned at 100°C by the Pressurized Ageing Vessel (PAV) for 20hr to simulate asphalt binder long-term ageing. Changes in stiffness (fatigue parameter $G^*.\sin\delta$) was determined by DSR on long-term aged modified samples to assesses the fatigue cracking property of binder at various intermediate temperatures.

To analyze the compatibility among modifiers and additives, the modified bitumen samples were conditioned under static heating at 180°C for 72hr. The conditioned samples were then cut into 3 equal parts, and top and bottom parts were tested for softening point temperature.

3 Results and Discussion

3.1 Conventional Performance Test Properties

Modified binders are tested for conventional performance properties and the results are compiled in Table 1. Modified binders' workability is important figure in asphalt mixture development thus dynamic viscosity was tested at both temperature 135°C and 165°C. Viscosity of all modified binders are within the allowable maximum value of 3.0 Pa.s.

Table 1. Conventional Performance Test Properties of Modified Binders

	PMB–A	PMB–B	PMB–C	PMB–D	Recycled Plastic (RP)
Viscosity at 135°C, Pa.s	1.635	1.665	1.970	2.620	2.340
Viscosity at 165°C, Pa.s	0.435	0.500	0.475	0.550	0.500
Softening Point, °C	89.0	96.0	88.5	93.0	94.5
Elastic Recovery at 25°C, %	89	95	99	99	0
Elastic Recovery at 25°C after RTFO, %	83	75	94	93	0
DSR G*/sin δ at 82°C, kPa	1.55	1.92	1.57	1.76	1.40
DSR G*/sin δ at 82°C after RTFO, kPa	2.31	2.47	2.39	2.74	2.33

Since bitumen is a viscoelastic material, it is normally softer and flow easily at high service temperature. Softening point temperature test indicate the temperature at which bitumen become softer and starts to flow. The softening point temperature also signify the high temperature performance in modified binders [10]. Softening point temperatures of all modified binders achieved above 85°C.

The presence of elasticity in PMB can be measured by the recoverable strain and express as elastic recovery of modified binder. The elastic recovery indicates the presence of polymer in PMB, but does not able to identify and quantify the modifiers used. Elastic recovery test was done before and after RTFO ageing and the results are shown in Table 3. Retained recovery percentage for all PMB is ranging between 91% and 94%. There is no elastic recovery result for RP modified binder.

At test temperature 82°C, G*/sin δ for all unaged and RTFO aged modified binders meet the specified value of minimum 1.0 kPa and 2.2 kPa accordingly with AASHTO M320. As such, all modified binders qualify as Superpave performance grade PG82 binders.

3.2 Compatibility

Compatibility between polymer and base binder was investigated by storage stability test. Large difference in softening point temperature between top and bottom of test samples highlight degree of incompatibility [11]. Figure 2 showed that all polymer modified samples are stable with difference of less than 5°C while the recycled-plastic modified binder showed poor stability with a large difference of 54.5°C.

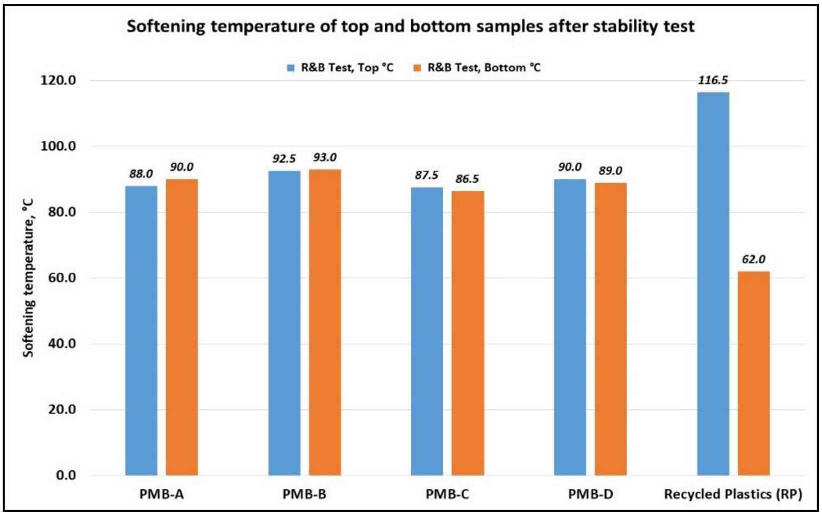

Fig. 2. Storage stability of modified binders

3.3 Fatigue Cracking Resistance by DSR (G*.sin δ)

Modified binder samples are long-term aged using the Pressurized Ageing Vessel (PAV) to evaluate fatigue cracking performance. DSR G*. sin δ was carried out at various intermediate temperatures such as 40, 37, 34, 31 and 28°C which represent minimum pavement design temperatures at -10, -16, -22, -28 and -34°C respectively for PG 82 binders. Test results were compared to the maximum limit specified in AASHTO M320 (max 5000 kPa) and AASHTO M332 (max 6000 kPa) as summarized in Figure 3.

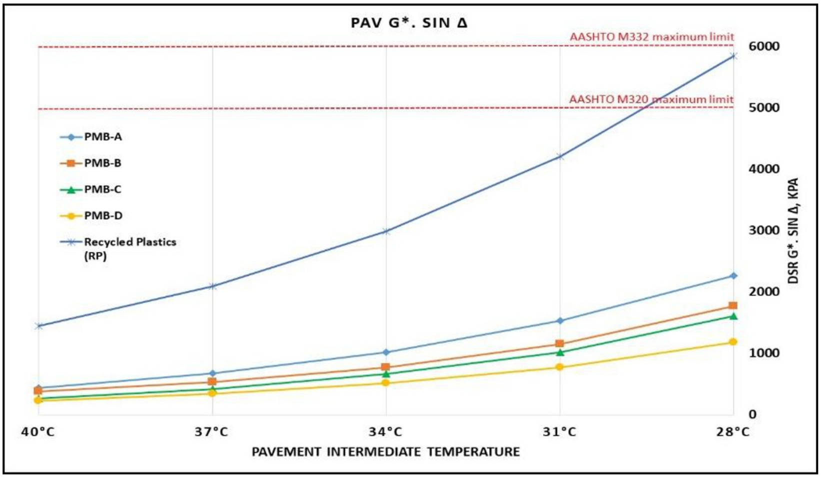

Fig. 3. Changes in stiffness of modified binders by long-term ageing

All PMB samples showed lower values of G*.sin δ while RP modified binder resulted high values from 28°C to 40°C. Which imply that the PMB binders provide better fatigue cracking resistance than the RP modified binder. By comparing G*.sin δ value at 28°C (which correspond to a minimum pavement design temperature of -34°C according to AASHTO M320 [1] and M332 [4]), that of RP modified binder exceeded the maximum requirement of 5000 kPa (based on AASHTO M320) while PMB samples are well below the maximum requirement.

3.4 MSCR

(a) $J_{nr3.2}$, the non-recoverable creep compliance at 3.2kPa, was determined for all modified binders at 82°C. As shown in Figure 4, PMB-C and PMB-D samples showed the lowest $J_{nr3.2}$ value (i.e. high rutting resistance) at 0.0961kPa^{-1} and 0.158kPa^{-1} while RP sample show the highest value of 4.4832 (low rutting resistance).

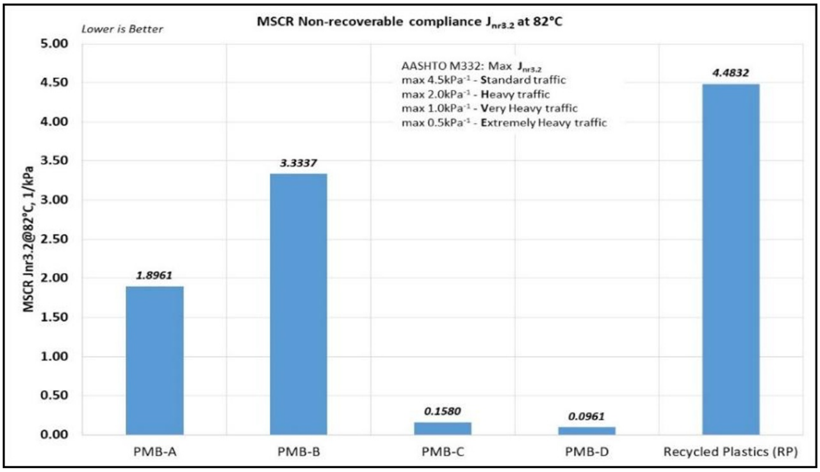

Fig. 4. $J_{nr3.2}$ of modified binders

According to AASTHO M332 [4], binders can be selected in different designation grades according with the expected traffic level and load rate by resulted $J_{nr3.2}$ value as shown in Table 2.

Table 2. AASHTO M332 specification [4]

Designation grade	Traffic level (ESALs)		Traffic load rate	$J_{nr3.2}$
Standard traffic 'S'	<10 million	and	> 70 km/h	max 4.5 kPa^{-1}
Heavy traffic 'H'	10 – 30 million	or	20 – 70 km/h	max2.0 kPa^{-1}
Very heavy traffic 'V'	> 30 million	or	< 20 km/h	max1.0 kPa^{-1}
Extremely heavy traffic 'E'	> 30 million	and	< 20 km/h	max0.5 kPa^{-1}

Base on Table 3, PMB-C and PMB-D will be classified as grade "E", PMB-A will be grade "H" while PMB-B and PMB-E will be grade "S".

(b) Apart from J_{nr}, the MSCR test measures J_{nrdiff} which is the percentage difference between J_{nr} at 0.1 kPa and 3.2 kPa stress levels. This property is intended to quantify the sensitivity to changes in stress level under specific temperature. Figure 5 summarizes the J_{nrdiff} of the modified binders.

According to AASTHO M332 [4], a maximum limit of 75% was specified for J_{nrdiff} to set as a safety factor for binder where pavement may experience higher loading stress or higher than normal temperature. However, challenges have been reported meeting with this J_{nrdiff} limit of 75% especially for binder grade with $J_{nr3.2}$ less than 0.5 kPa-1 [12]. It should be noted that lower J_{nrdiff} indicate the lesser stress sensitivity of modified binders and the limit is not required for J_{nr} values of lower than 0.5 kPa-1 based on the latest AASHTO M332. Results from Figure 5 showed that PMB-A and PMB-B samples are more stress sensitive compared to PMB-C, PMB-D and RP samples.

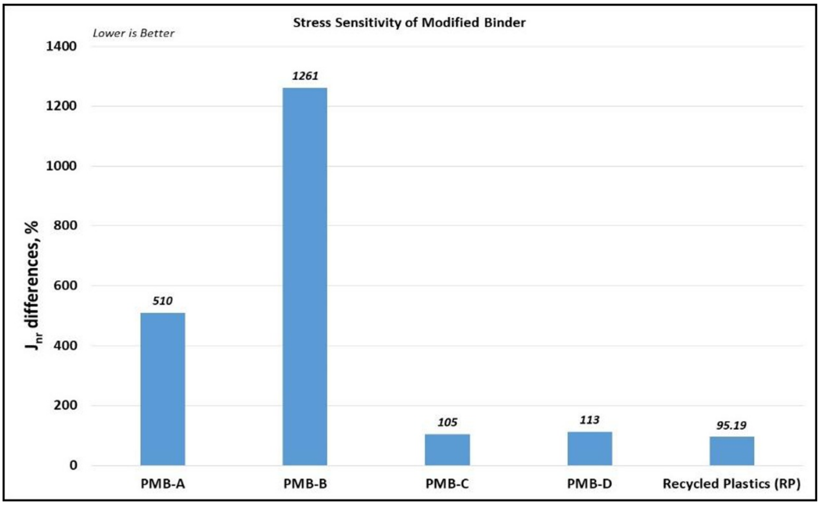

Fig. 5. Stress sensitivity of modified binders

(c) Last but not least, the MSCR also measures the percent recovery ($R_{3.2}$) which provides the elastic response of binder during shear creep and recovery at specific temperature. The results are summarized in Figure 6. The $R_{3.2}$ results indicated that all modified samples showed elastic response except for the RP modified sample. Among the PMB samples, PMB-C and PMB-D samples showed the highest $R_{3.2}$ results of more than 90%.

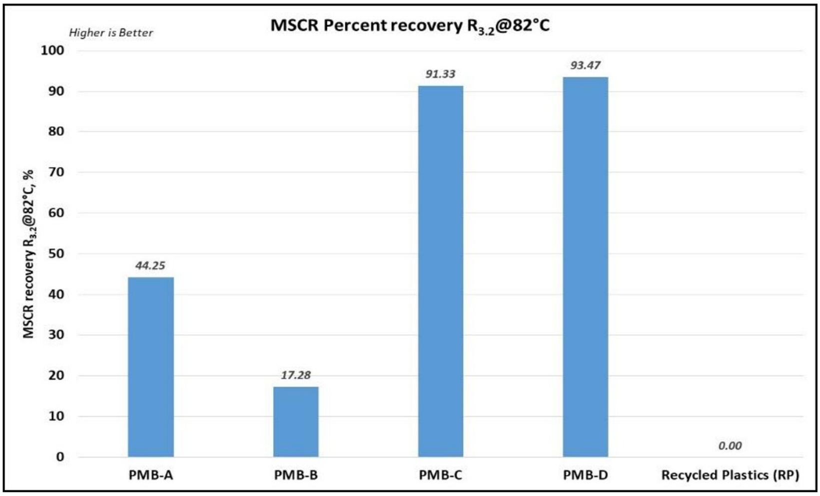

Fig. 6. MSCR Percent Recovery @ 3.2kPa of modified binders

According to AASHTO R92 [13], the percent $R_{3.2}$ of the binder can be analyzed with respect to the associated Jnr value based on the curve shown in Figure 7. Data that lies on or above the curve is classified as demonstrating a notable elastic response at the respective value of J_{nr}. If $J_{nr3.2}$ less than 0.1, $R_{3.2}$-min value will be 55% and if $J_{nr3.2}$ is more than 2.0, $R_{3.2}$-min value will be 0%.

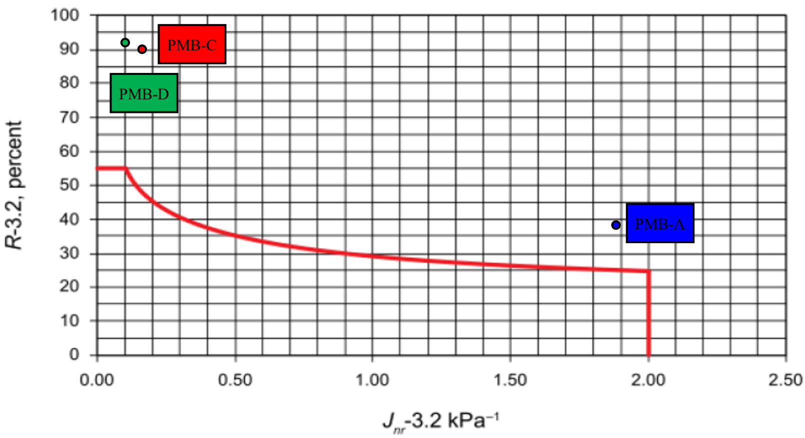

Fig. 7. Assessment of elastic response by MSCR $J_{nr3.2}$ and $R_{3.2}$ [13]

From Figure 7, PMB-A, PMB-C and PMB-D samples showed significant elastic response except PMB-B and RP modified binder samples.

4 Summary of Results

Table 3 summarized the performance properties of all modified binders. The results showed that even though all modified binders meet the Superpave PG 82 high temperature specification requirements, their rutting performance and fatigue cracking resistance are significantly different based on the MSCR test and fatigue cracking test after long term ageing by PAV. Among the PMB samples, PMB-D sample performed the best with the lowest $J_{nr3.2}$ ("E" grade), high percent recovery ($R_{3.2}$) and low stress sensitivity while PMB-B sample showed poorest performance with the highest Jnr3.2 ("S" grade), lowest percent recovery and high stress sensitivity. On the other hand, RP sample exhibited the high $J_{nr3.2}$ ("S" grade), zero percent recovery and low stress sensitivity.

Table 3. Performance grading of modified binders

Sample ID	Max pavement design temp: 82°C	Intermediate temp based on PAV test	MSCR $J_{nr3.2}$ (kPa^{-1})	MSCR $R_{3.2}$ (%)	Stress sensitivity	MSCR grade
PMB-A	✓	≤28°C	1.8961	44.25	yes	H
PMB-B	✓	≤28°C	3.3337	17.28	yes	S
PMB-C	✓	≤28°C	0.1580	91.33	no	E
PMB-D	✓	≤28°C	0.0961	93.47	no	E
RP	✓	31°C	4.4832	0.00	no	S

In the case of fatigue cracking, the PMB samples are more resistant to cracking as compared to the RP modified sample. As compared to RP sample, the PMB samples also showed lower minimum intermediate temperature based on PAV tests.

5 Conclusions and Recommendations

The summarized results validated that the same PG 82 grade binders can perform significantly different when tested by MSCR test. Some of the fundamental differences identified in this study are highlighted as follows:

- Rutting performance based on J_{nr} (MSCR) – Rutting performance exhibits substantial variations although all binders are rated as PG 82.
- Stress sensitivity based on J_{nrdiff} (MSCR) - Some modified binders are more stress sensitive than others.
- Elastic response based on percent recovery (MSCR) – Different modified binders significantly show different elastic response.

Apart from MSCR test, the fatigue cracking test using the DSR to determine the $G^*.\sin\delta$ after long term ageing by PAV also revealed that the PMB samples showed higher crack resistance than RP sample at intermediate temperatures. The results validated that both the MSCR and DSR G*.sin δ (after PAV) tests can more accurately assess and specify the characteristic of modified binders.

Based on the above conclusions, it is recommended to incorporate the MSCR and DSR G*.sin δ (after PAV) tests into the current PG binder specification in Singapore. Enhancing the binder specification, will allow for a more accurate assessment of PMBs, ultimately contributing to more durable and sustainable asphalt pavements. Further study will be conducted to verify the findings based on asphalt mixture performance.

References

1. American Association of State Highway and Transportation Officials (AASHTO). "Standard Specification for Performance-Graded Asphalt Binder." AASHTO M320-23, Washington, DC. 2023.
2. D'Angelo, J., and Dongre, R. (2002). "Superpave binder specifications and their performance relationship to modified binders." Annual Conf. of the Canadian Technical Asphalt Association, Polyscience Publications, Laval, QC, Canada
3. Dongré, R., and D'Angelo, J. (2003). "Refinement of superpave high temperature binder specification based on pavement performance in the accelerated loading facility." Transp. Res. Rec., 1829, 39–46.
4. American Association of State Highway and Transportation Officials (AASHTO). "Standard Specification for Performance-Graded Asphalt Binder Using Multiple Stress Creep Recovery (MSCR) Test." AASHTO M332-23, Washington, DC. 2023.
5. D'Angelo, J. (2009). "Development of a performance based binder specification for rutting using creep and recovery testing." Ph.D. dissertation, Univ. of Calgary, Alberta, Canada.
6. D'Angelo, J. (2010). "New high-temperature binder specification using multi-stress creep and recovery." E-Circular E-C147, Transportation Research Board, Washington, DC, 1–13 Akshay Gundla, Shane Underwood. Interpreting Stress Sensitivity in the Multiple-Stress Creep and Recovery Test.
7. Jafari M. and Babazadeh A. 2015. "Evaluation of Polyphosphoric Acid-modified Binders Using Multiple Stress Creep and Recovery and Linear Amplitude Sweep Tests". Road Materials and Pavement Design,17: 4,859876, DOI:10.1080/14680629.2015.1132631
8. Wahhab H. I. Al-Abdul, M. A. Dalhat, and M. A. Habib. 2016. "Storage Stability and High-temperature Performance of Asphalt Binder Modified with Recycled Plastic". Road Materials and Pavement Design
9. Win Maung.A. N, Tiah, G.W. Lee. Y.P.K. and Ho. N.Y. "Effects of Recycled Plastic on the Performance of Polymer Modified Bitumen (PMB) – Long-term Ageing and Fatigue". 2023
10. Liliana M.B. costa., Hugo M.R.D. Silva., Joel R.M. Oliveira., Sara R.M. Fernandes. (2016) Incorporation of Waste Plastic in Asphalt Binders to Improve their Performance in the Pavement. International Journal of Pavement Research and Technology, vol:6 No.4. Jul (2016).
11. The British Standards Institution (BSI). "Bitumen and Bituminous Binders-Determination of Storage Stability of modified bitumen". BS EN 13399-17, United Kingdom. 2017.
12. Jeffrey Stempihar, Akshay Gundla, and B. Shane Underwood.: (2017) Interpreting Stress Sensitivity in the Multiple Stress Creep and Recovery Test. American Society of Civil Engineers.

13. American Association of State Highway and Transportation Officials (AASHTO). "Standard Practice for Evaluating the Elastic Behavior of Asphalt Binders Using the Multiple Stress Creep Recovery (MSCR) Test". AASHTO R92-18, Washington, DC. 2018.