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Critical Assessment of the Multiple Creep Stress Recovery (MSCR) Test on Bitumen Performance a Comparative Experimental Study

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Abstract

Conventional DSR high-temperature performance grading uses G*/sin delta to characterise small-strain oscillatory binder response but does not directly quantify residual strain after repeated loading. This study presents a same-formulation comparison of DSR grading and multiple stress creep recovery (MSCR) response for 60/70 penetration-grade bitumen modified with 6% linear styrene-butadiene-styrene (SBS) and 1.5% Sasobit. The available laboratory record comprised a DSR temperature sweep assessed using the original-binder criterion G*/sin delta ≥ 1.0 kPa and MSCR testing at 76°C under 0.1 and 3.2kPa. Instrument outputs for percent recovery (%R_3.2), non-recoverable creep compliance (J_nr3.2) and stress sensitivity (J_nr-diff) were extracted and interpreted against AASHTO M 332 thresholds. The DSR continuous pass/fail temperature was 95.6°C. Recovery decreased from 93.61% at 0.1kPa to 59.55% at 3.2kPa, while J_nr3.2 increased from 0.0524 to 0.4852kPa^{-1}. Although J_nr3.2 was below the commonly used 0.5kPa^{-1} threshold for an E traffic suffix, J_nr-diff was 825.38%, indicating pronounced stress sensitivity. The paper's contribution is to show, for the same modified binder, that a favourable DSR grade and low J_nr3.2 can coexist with a stress-sensitivity concern that would be missed if either result were interpreted alone. The findings do not establish mixture or field rutting performance. Since only one formulation and no replicate-level data were available, Malaysian specification use requires documented preparation and ageing, replicate testing, justified test temperature, mixture-level validation and field monitoring.

Keywords: Multiple Creep Stress Recovery, MSCR, AASHTO T350, Critical Bitumen Performance Assessment

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1 Introduction

1.1 Background of Bitumen Performance Testing

Since the 1980s, the grading and specification of bitumen in Malaysia has primarily been based on penetration grading. The penetration-based approach is a conventional method used to classify bitumen based on its hardness. It measures the depth (in tenths of a millimetre) that a standard needle penetrates the bitumen sample under a load of 100 grams for 5 seconds at a standard temperature, typically 25°C.

However, it is worth noting that the penetration-based approach, while useful, has limitations and does not fully capture the complex viscoelastic behaviour of bitumen, especially under varying temperature and loading conditions.

Although penetration grading is a fundamental property of bitumen, it is not a reliable indicator of field performance. Rather, field performance is only empirically related to bitumen hardness. Many countries, including the USA, have adopted performance grading (PG) of paving-grade bitumen. Hence, the Malaysian Public Works Department (JKR) first announced the specification for Performance Grading (PG) of bitumen in 2008. This move was part of an effort to align Malaysia's road construction standards with more advanced and performance-oriented testing methods, including the DSR test method, like those adopted in countries like the United States under the Superpave system. This specification aimed to improve the quality and durability of pavements in varying climatic conditions across Malaysia.

However, the issue with the Performance Grading (PG) system not adequately reflecting actual rutting and cracking resistance led to the development and adoption of the Multiple Stress Creep Recovery (MSCR) test in the mid-2000s. The Federal Highway Administration (FHWA) and other associated research bodies identified these shortcomings and began refining the testing methods to better predict real-world pavement performance.

By 2010, the MSCR test was formally incorporated into AASHTO (American Association of State Highway and Transportation Officials) specifications, making it a standard method for evaluating the performance of asphalt binders, particularly focusing on their rutting resistance under various stress and temperature conditions. The MSCR test provided a more accurate assessment, thus addressing the gaps left by previous PG methods.

2 Objective

The main objective of this research is to distinguish the limitations of the DSR test and explore the relationship between MSCR test parameters and bitumen's rutting resistance. Through analysis of the MSCR test data, this study aims to offer valuable insights into the viscoelastic behaviours of bitumen and its impact on pavement performance. The study also assesses how MSCR parameters characterise the binder's high-temperature deformation response and stress sensitivity compared with conventional DSR grading, underscoring the significance of viscoelastic properties in optimising asphalt pavement performance and offering valuable guidance for pavement design and maintenance.

3 MSCR Test Methodology

The MSCR procedure specified in AASHTO T 350 comprises ten conditioning cycles at 0.1kPa, followed by ten recorded creep-recovery cycles at 0.1kPa and ten at 3.2kPa. Each cycle consists of 1 s of loading and 9 s of recovery, as specified by the FHWA. For this study, the laboratory output reports testing at 76°C and provides percent recovery (*%R_3.2*) and non-recoverable creep compliance (*J_nr3.2*). *J_nr3.2* is not creep-stiffness. However, although a total of 20 binder specimens were prepared and the binder was tested in its original and RTFO-aged conditions, protocols for replicate testing, conditioning, and temperature equilibration were not documented. These omissions prevent independent assessment of repeatability and full reproduction of the test. The reported results are therefore interpreted as descriptive values for the tested formulation rather than statistically validated performance measures.

3.1 MSCR Test

The Multiple Stress Creep Recovery (MSCR) test uses a creep-and-recovery concept in accordance with AASHTO T 350 to evaluate the binder's potential for permanent deformation. The Dynamic Shear Rheometer (DSR), which is the same type of equipment used today in the existing PG specification, is used to conduct the test. In this procedure, the sample is tested at a temperature of 76°C and a one-second creep load is applied to an asphalt binder sample, followed by the removal of the load for 9 seconds. Figure 1 displays typical data for a modified binder. The MSCR test begins with the application of a low stress (0.1kPa) for 10 cycles and then increases the stress to 3.2kPa, repeating this process for an additional 10 cycles.

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The material response in the MSCR test is significantly different from the response in the existing PG tests. In the PG system, the high temperature parameter, G*/sin, is measured by applying an oscillating load to the binder at very low strain. Due to the low strain level, the PG high temperature parameter doesn't accurately represent the ability of the modified binders to resist rutting.

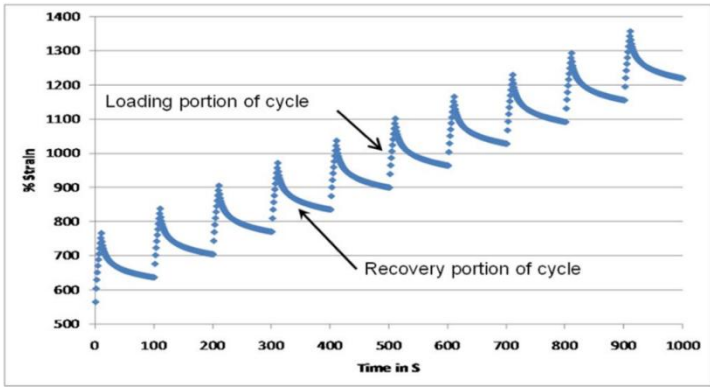


Figure 1. Typical response of a polymer-modified asphalt binder to repeated MSCR loading. Reproduced from Federal Highway Administration

Figure 1 illustrates the accumulation and partial recovery of strain during repeated MSCR loading cycles. Each loading period produces an increase in strain, followed by partial recovery after the stress is removed. The strain remaining at the end of the recovery period is used to calculate non-recoverable creep compliance (*J_nr3.2*), while the recovered portion is expressed as percent recovery (*%R_3.2*). Unlike the small-amplitude oscillatory loading used to determine G*/sin delta, MSCR testing examines binder response under repeated creep and recovery at different stress levels. These parameters describe the binder's recovery, non-recoverable deformation and stress sensitivity under the test conditions; they do not independently establish mixture or field rutting performance [3].

Under the very low levels of stress and strain present in dynamic modulus testing, the modifier bitumen network is never really activated. In the existing PG specification, the modifier bitumen is only measured as a filler that stiffens the asphalt. In the MSCR test, higher levels of stress and strain are applied to the binder where the key parameters, such as percent recovery (*%R_3.2*) and non-recoverable creep compliance (*J_nr 3.2*), better represent what occurs in an actual pavement. By using the higher levels of stress and strain in the MSCR test, the response of the asphalt binder captures not only the stiffening effects of the bitumen, but also the delayed elastic effects (where the binder behaves like a rubber band).In MSCR testing, non-recoverable creep compliance (*J_nr3.2*) indicates the binder's ability to resist permanent deformation (rutting); see Figure 2.

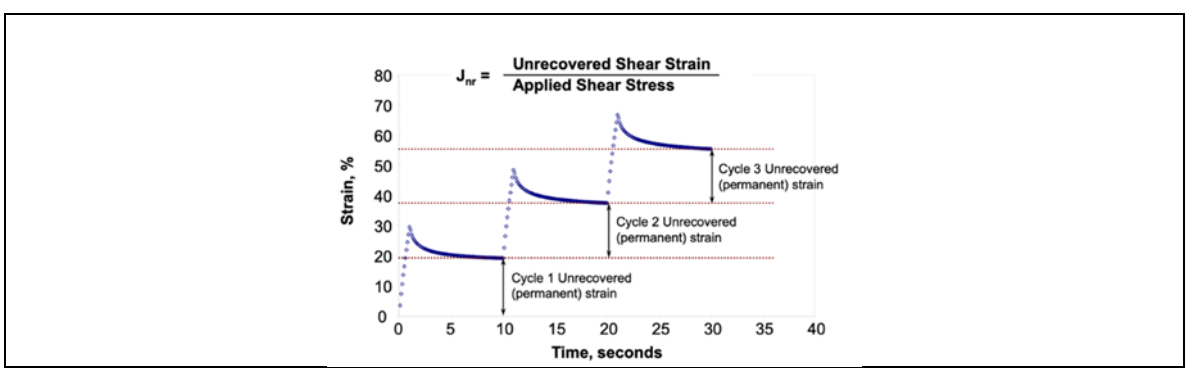


Figure 2. MSCR Non-recoverable Creep Compliance (*J_nr3.2*)

J_nr3.2 addresses the high-temperature rutting performance of both neat (unmodified) and modified binders, while the recovery value adds another dimension by evaluating the elastic recovery of the binder. This becomes crucial under high-stress conditions where the binder needs to exhibit both stiffness to resist rutting and elasticity to recover from deformation. Binders with a high *%R_3.2* are better equipped to withstand the repeated loading and unloading cycles typical of heavy traffic, thereby reducing the likelihood of permanent deformation (rutting).

Percent recovery (*%R_3.2*) represents the binder's elasticity, or its ability to return to its original shape after deformation, as shown in Figure 3. Expressed as a percentage, it quantifies the elastic response of the bitumen once the load is removed. It is calculated based on the amount of deformation the binder recovers during the 9-second recovery period following a 1-second application of creep stress.

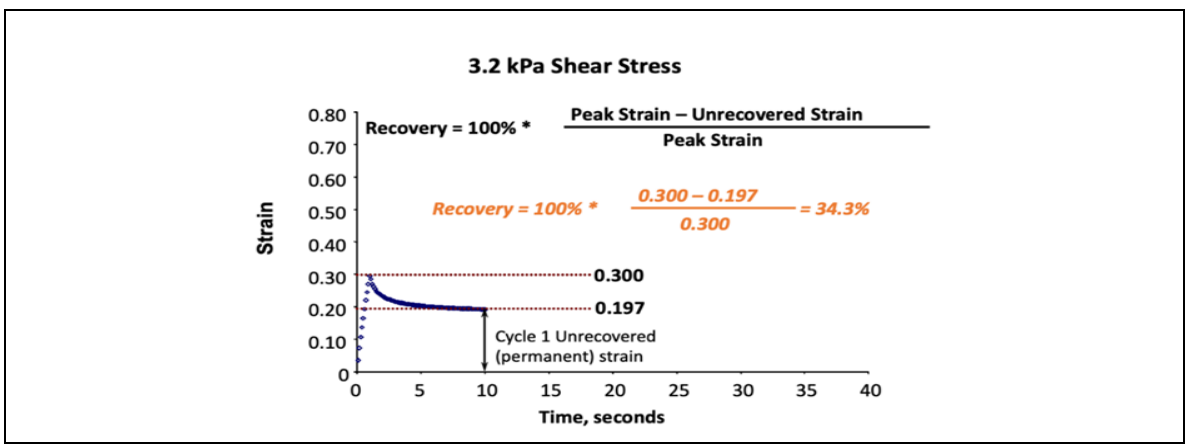


Figure 3. MSCR Percentage of Recovery (*%R_3.2*)

The Recovery value (*%R_3.2*) quantifies the amount of deformation the binder regains during the recovery phase compared to the total deformation sustained during the loading phase. This parameter is particularly beneficial for highway agencies that use polymers in asphalt binders to enhance cracking resistance and durability. Polymers like Styrene-Butadiene-Styrene (SBS) are added to bitumen to improve its elastic properties. The *%R_3.2* measurement effectively identifies and quantifies the performance of these polymers within the binder. A higher Recovery value indicates significant elastic recovery, showcasing the polymer's contribution to the binder's ability to resist permanent deformation and cracking.

4 DSR (Performance Grading) Vs MSCR

The DSR temperature sweep produced a continuous high-temperature pass/fail temperature of 95.6°C, indicating a high (G*/sin delta) response under the reported oscillatory test conditions. MSCR provides additional information by measuring non-recoverable deformation and recovery under repeated loading. Table 1 compares the measured (*J_nr3.2*) value with the traffic-designation thresholds in AASHTO M 332 [2].

Table 1. Comparison of the measured MSCR result with AASHTO M 332 traffic thresholds

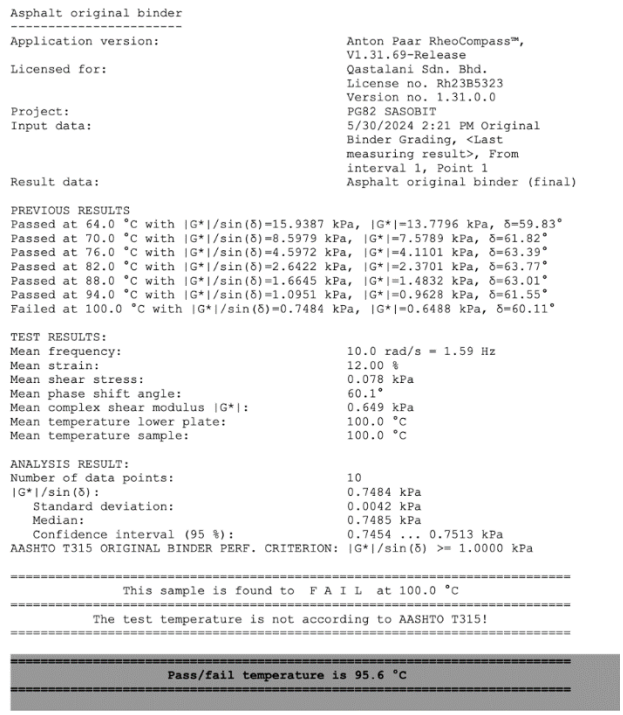
Designation	Traffic level	Maximum *J_nr3.2* (kPa^{-1})	Comparison with measured value
S	Standard	4.5	Meets
H	Heavy	2.0	Meets
V	Very heavy	1.0	Meets
E	Extremely heavy	0.5	Meets narrowly

The measured *J_nr3.2* of 0.4852kPa^{-1} at 76°C is below the 0.5kPa^{-1} limit for the E designation and therefore meets the published J_nr3.2 criterion on a numerical basis. However, the margin below the limit is only 0.0148 kPa^{-1}. Furthermore, the reported *J_nr-diff* of 825.38% indicates pronounced stress sensitivity. Since the binder ageing condition, replicate results, measurement uncertainty and project-specific traffic and pavement temperature selection were not documented, the E designation should be treated as a provisional comparison rather than confirmed specification compliance. The reported *%R_3.2* of 59.55% describes elastic recovery but does not independently determine the M 332 traffic designation. These binder-level results also do not establish mixture or field rutting performance.

4.1 Malaysia studies on DSR (Performance Grading) Vs MSCR

All blending and rheological testing reported here were conducted in the authors' laboratory using an Anton Paar DSR [5]. The formulation contained 60/70 penetration-grade bitumen, 6% linear SBS and 1.5% Sasobit. The same-formulation comparison shows what each test reports; it is not a controlled study of additive effects because no unmodified control, formulation series or replicate dataset was available.

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Asphalt original binder
-----------------------
Application version:                    Anton Paar RheoCompass™,
                                        V1.31.69-Release
Licensed for:                           Qastalani Sdn. Bhd.
                                        License no. Rh23B5323
                                        Version no. 1.31.0.0
Project:                                PG82 SASOBIT
Input data:                             5/30/2024 2:21 PM Original
                                        Binder Grading, <Last
                                        measuring result>, From
                                        interval 1, Point 1
Result data:                            Asphalt original binder (final)

PREVIOUS RESULTS
Passed at 64.0 °C with |G*|/sin(δ)=15.9387 kPa, |G*|=13.7796 kPa, δ=59.83°
Passed at 70.0 °C with |G*|/sin(δ)=8.5979 kPa, |G*|=7.5789 kPa, δ=61.82°
Passed at 76.0 °C with |G*|/sin(δ)=4.5972 kPa, |G*|=4.1101 kPa, δ=63.39°
Passed at 82.0 °C with |G*|/sin(δ)=2.6422 kPa, |G*|=2.3701 kPa, δ=63.77°
Passed at 88.0 °C with |G*|/sin(δ)=1.6645 kPa, |G*|=1.4832 kPa, δ=63.01°
Passed at 94.0 °C with |G*|/sin(δ)=1.0951 kPa, |G*|=0.9628 kPa, δ=61.55°
Failed at 100.0 °C with |G*|/sin(δ)=0.7484 kPa, |G*|=0.6488 kPa, δ=60.11°

TEST RESULTS:
Mean frequency:                         10.0 rad/s = 1.59 Hz
Mean strain:                            12.00 %
Mean shear stress:                      0.078 kPa
Mean phase shift angle:                 60.1°
Mean complex shear modulus |G*|:        0.649 kPa
Mean temperature lower plate:           100.0 °C
Mean temperature sample:                100.0 °C

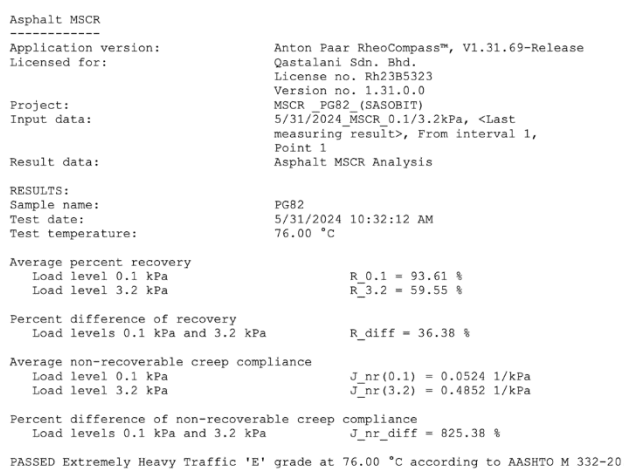
ANALYSIS RESULT:
Number of data points:                  10
|G*|/sin(δ):                           0.7484 kPa
   Standard deviation:                  0.0042 kPa
   Median:                              0.7485 kPa
   Confidence interval (95 %):          0.7454 ... 0.7513 kPa
AASHTO T315 ORIGINAL BINDER PERF. CRITERION: |G*|/sin(δ) >= 1.0000 kPa

========================================================================
              This sample is found to  F A I L  at 100.0 °C
========================================================================
          The test temperature is not according to AASHTO T315!
========================================================================

========================================================================
                    Pass/fail temperature is 95.6 °C
========================================================================
```

Figure 4. DSR (Performing Grading) test show the binder failed at highest temperature 95.6°C

Figure 4 shows that G*/sin δ remained above 1.0kPa at 94 °C and fell below the criterion at 100 °C, giving a continuous pass/fail temperature of 95.6 °C. This is a rheological threshold for the reported test condition, not the temperature at which a pavement or binder suddenly fails. It also does not, by itself, establish rutting resistance, durability or the separate effects of SBS and Sasobit.



```
Asphalt MSCR
------------
Application version:              Anton Paar RheoCompass™, V1.31.69-Release
Licensed for:                     Qastalani Sdn. Bhd.
                                  License no. Rh23B5323
                                  Version no. 1.31.0.0
Project:                          MSCR _PG82_(SASOBIT)
Input data:                       5/31/2024 MSCR_0.1/3.2kPa, <Last
                                  measuring result>, From interval 1,
                                  Point 1
Result data:                      Asphalt MSCR Analysis

RESULTS:
Sample name:                      PG82
Test date:                        5/31/2024 10:32:12 AM
Test temperature:                 76.00 °C

Average percent recovery
   Load level 0.1 kPa                       R_0.1 = 93.61 %
   Load level 3.2 kPa                       R_3.2 = 59.55 %

Percent difference of recovery
   Load levels 0.1 kPa and 3.2 kPa          R_diff = 36.38 %

Average non-recoverable creep compliance
   Load level 0.1 kPa                       J_nr(0.1) = 0.0524 1/kPa
   Load level 3.2 kPa                       J_nr(3.2) = 0.4852 1/kPa

Percent difference of non-recoverable creep compliance
   Load levels 0.1 kPa and 3.2 kPa          J_nr_diff = 825.38 %

PASSED Extremely Heavy Traffic 'E' grade at 76.00 °C according to AASHTO M 332-20.
```

Figure 5. MSCR test show the binder recovery %R_3.2 is 59.55% and J_nr3.2 is 0.4853 1/kPa

In our next analysis, Figure 5 reports *%R_3.2* = 59.55% and *J_nr3.2* = 0.4852kPa^{-1} at 76 °C. *J_nr3.2* meets the E threshold numerically but lies close to the limit. The software-reported J_nr-diff of 825.38% shows marked stress sensitivity between the two stress levels.

In conclusion, the comparison between DSR (performance grading) and MSCR tests demonstrates that a favourable DSR outcome, while indicative of overall performance, does not guarantee high recovery (*%R_3.2*) and low non-recoverable creep (*J_nr3.2*) values. These parameters are essential for accurately predicting a bitumen's resistance to rutting, highlighting the need for a comprehensive evaluation of modified bitumen's performance under various conditions.

4.2 Previous Studies about Rutting Criteria with MSCR "*J_nr 3.2*"

The FHWA Accelerated Loading Facility evaluated full-scale pavement sections containing neat, air-blown, SBS-modified, crumb-rubber-modified and Elvaloy modified binders. The sections were heated to 64°C and trafficked with a 10,000-lb super-single tyre. Measured rutting was compared with the Superpave parameter G*/sin δ and the MSCR parameter *J_nr3.2* (Figures 6 and 7).

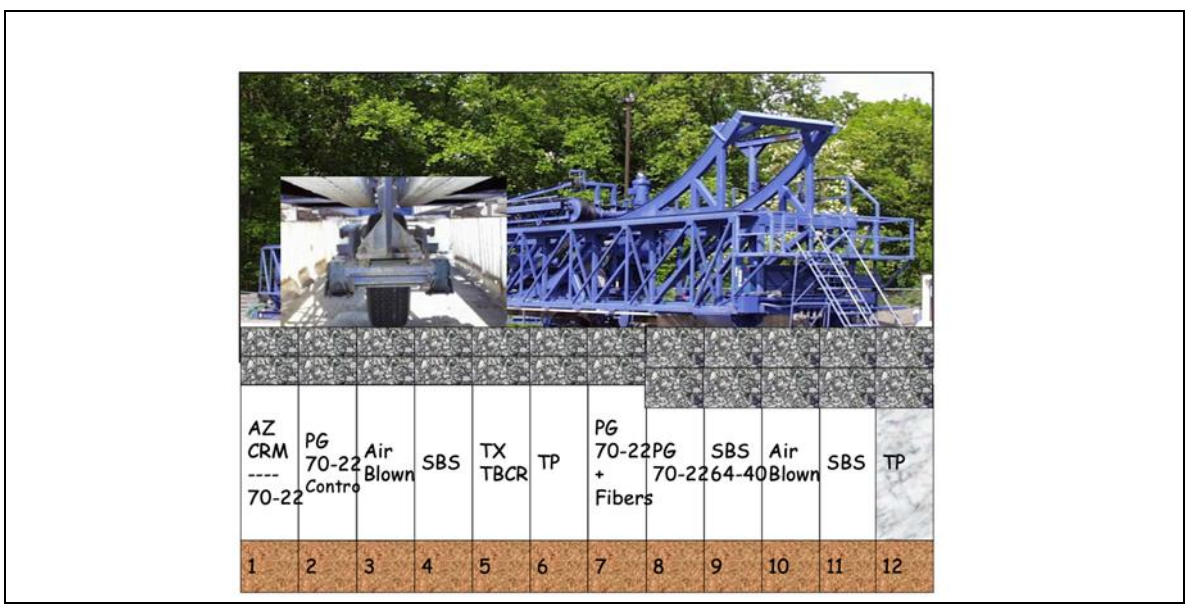


Figure 6. Various Asphalt Binder Evaluated with the ALF and G*/sin& as Compared with the MSCR.

The ALF results demonstrated that *J_nr3.2* exhibited a stronger relationship with measured rutting performance than G*/sin δ. In particular, the *J_nr3.2* parameter obtained from the MSCR test showed a closer correlation with rutting resistance, indicating its greater sensitivity to permanent deformation behaviour. In contrast, the relationship between G*/sin δ, obtained from DSR testing, and measured rut depth was relatively weak. These findings suggest that *J_nr3.2* provides a more representative indicator of asphalt binder rutting performance under the evaluated conditions.

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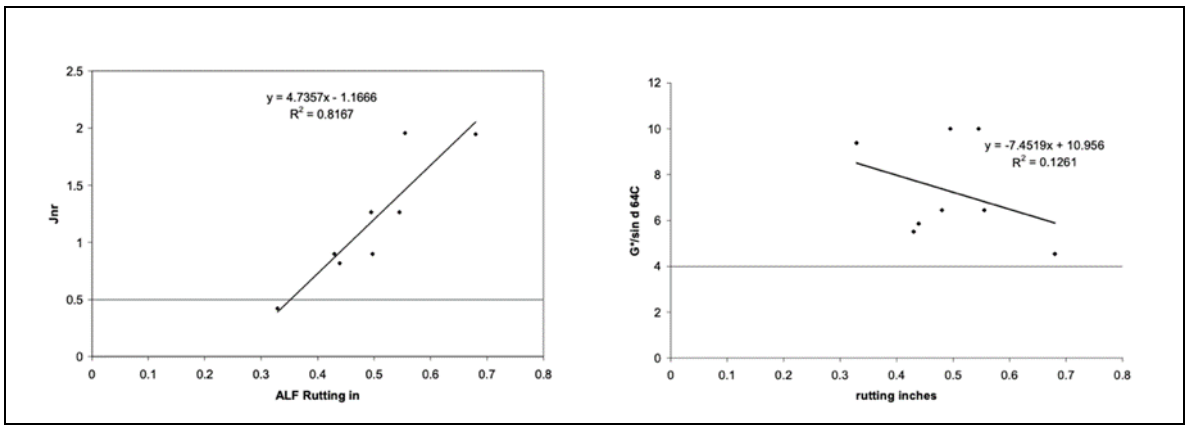


Figure 7. Comparison of Asphalt Binder Rutting Performance Evaluated Using ALF, $G^*/sin\ sin\ \delta$, and MSCR Parameters

The findings from the ALF evaluation were further supported by six years of field monitoring of test sections along Interstate 55 in Mississippi. The long-term field observations showed that *J_nr3.2* maintained a stronger relationship with observed pavement rutting than G*/sin δ, as presented in Figure 8. This consistency between accelerated laboratory evaluation and long-term field performance provides further evidence of the suitability of the MSCR parameter *J_nr*3.2 for evaluating the rutting susceptibility of asphalt binders.

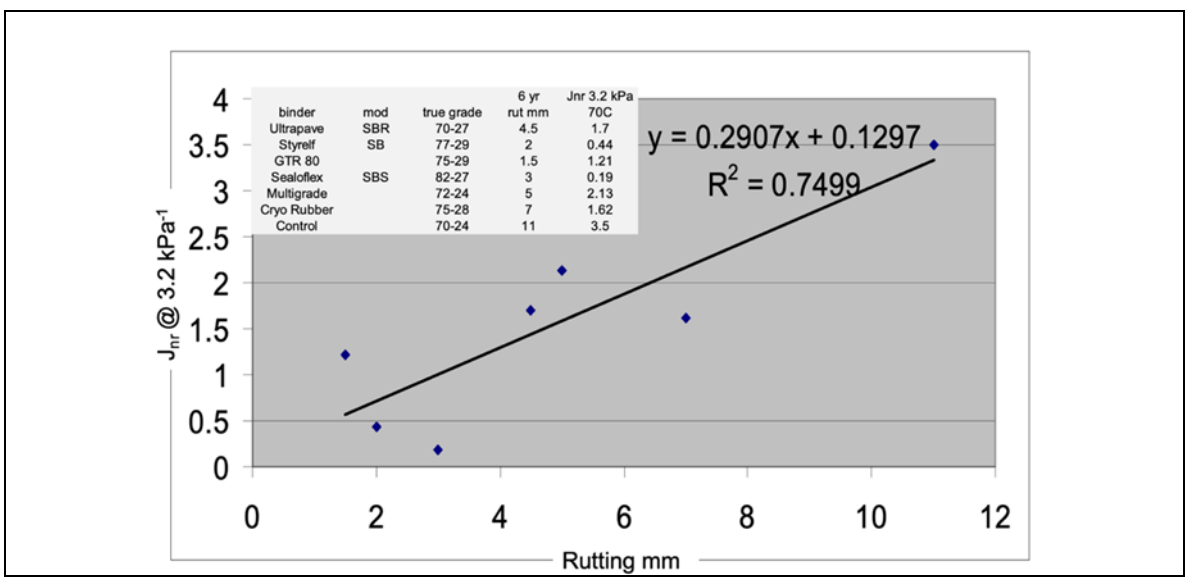


Figure 8. Rutting On I-55 Mississippi vs *J_nr3.2*

4.3 Discussion on above data and studies

The present results show that a satisfactory DSR high-temperature grade does not necessarily indicate a stress-insensitive binder. Although the tested binder achieved a high DSR pass/fail temperature and a low *J_nr3.2*, its recovery *(%R_3.2)* decreased as stress increased, while *J_nr-diff* indicated marked stress sensitivity. DSR and MSCR therefore describe different aspects of high temperature binder behaviour.

Recent international studies support this interpretation. Wang et al. [17] found that preloading and stress level affected *%R_3.2* and *J_nr3.2*, particularly for polymer modified binders, while some interlaboratory results did not meet AASHTO precision criteria. Zhou et al. [12] also found that the MSCR response of SBS modified binders depended on stress level and polymer structure. These findings show that *J_nr3.2* should be considered together with recovery *(%R_3.2)* and stress sensitivity.

Fares et al. [18] reported that the MSCR rankings of plant produced high polymer binders changed with temperature and stress and did not always match the mixture level performance ranking. Thus, recent evidence supports MSCR as a useful complement to DSR but confirms that neither test alone predicts field performance. Malaysian implementation should therefore include controlled ageing, replicate testing, locally relevant temperatures, mixture rutting tests and field validation.

5 Conclusion

The in-house testing produced a clear difference between the DSR and MSCR assessments of the same laboratory-prepared binder formulation containing 60/70 penetration-grade bitumen, 6% linear SBS and 1.5% Sasobit. The DSR temperature sweep passed the original-binder criterion at 94°C, failed at 100°C and produced a continuous pass/fail temperature of 95.6°C. However, MSCR testing at 76°C showed that recovery decreased from 93.61% at 0.1kPa to 59.55% at 3.2kPa, a reduction of 34.06 percentage points. Over the same stress increase, *J_nr3.2* rose from 0.0524 to 0.4852kPa^{-1}, approximately 9.3 times the low-stress value. The software-reported *J_nr-diff* of 825.38% confirms that the binder response was highly stress-sensitive.

The measured *J_nr3.2* of 0.4852kPa^{-1} was only 0.0148kPa^{-1}, or 2.96%, below the AASHTO M 332 limit of 0.5kPa^{-1} for the E traffic designation. This narrow margin, together with the high *J_nr-diff*, means that the E classification should be considered provisional until repeatability and ageing conditions are verified. The results show that a high DSR continuous-grade temperature does not necessarily indicate stable performance when the binder is subjected to higher repeated stress. MSCR therefore provides additional evidence on recovery, non-recoverable deformation and stress sensitivity that cannot be obtained from the DSR grading result alone. Neither test, however, independently predicts cracking, mixture rutting or pavement service life.

For implementation in Malaysia, MSCR should first be introduced as a supplementary requirement to DSR grading through a controlled pilot programme. Testing should use RTFO-aged binder, project-specific pavement temperatures and at least three independently prepared replicate specimens for each binder-temperature condition. Laboratories should report the raw creep-recovery cycles, *%R_0.1, %R_3.2, J_nr0.1, J_nr3.2, J_nr-diff* and measurement variability. The binder results should then be compared with wheel-tracking or Hamburg-type mixture tests and monitored on matched Malaysian field sections. National acceptance limits should be adopted only after the pilot confirms laboratory repeatability and a defensible relationship between MSCR results, mixture deformation and field rutting.

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Declaration of Conflicting Interests

The author has declared that he has no conflicts of interest.

Author Contribution

Conceptualisation, Garrick Chong; Methodology, Garrick Chong; Validation, Garrick Chong; Analysis, Garrick Chong; Investigation, Garrick Chong; Resources, Garrick Chong; Data Curation, Garrick Chong; Writing—Original Draft Preparation, Garrick Chong; Writing—Review & Editing, Garrick Chong; Visualisation, Garrick Chong; Supervision, Garrick Chong; Project Administration, Garrick Chong; Funding Acquisition, Garrick Chong.

Declaration of Generative AI in the Writing Process

During the preparation of this manuscript, the author used ChatGPT for grammar checking. The author reviewed and edited the content as needed and takes full responsibility for the content of the publication.

Availability/Supplementary Materials

The DSR and MSCR numerical results analysed in this study are reported in the article. No supplementary dataset accompanies this manuscript.

Ethics Statement

This study involved laboratory testing of bituminous binders and did not involve human participants, animals or identifiable personal data. Ethical approval relating to human or animal research and informed consent were therefore not applicable.

The author accepts responsibility for the accuracy and integrity of the reported results, appropriate attribution of source materials, and transparent disclosure of methodological limitations. The findings are interpreted within the scope of the available laboratory records, without claiming independently verified specification compliance or field performance. Any material errors identified after publication will be reported to the journal for correction.

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