



Minnesota Department of Transportation

State Aid for Local Transportation, MS 500
395 John Ireland Boulevard
Saint Paul, MN 55155

Asphalt Binder Multiple Stress Creep Recovery (MSCR) Overview

(November 13, 2015)

Beginning January 1, 2016, Minnesota will implement the latest improvement to the PG grading system, Multiple Stress Creep Recovery (MSCR). See the document *Implementation of MSCR (Sept 2015)* which explains the what and why about the new specification. An explanation of the new guidelines is presented in the document entitled *PG MSCR Guidelines Final (November 12, 2015)*. The previous PG Guidelines were easily modified to readily accommodate the MSCR specification without much change. The same asphalt grade designation letters will be used to identify the grades with which you are familiar. For example, "B" will represent PG 58S -28 (old PG 58 -28) and "E" will represent PG 58H -28 (old PG 64 -28).

The primary change seen in asphalt binder grades is in the high temperature grade. The new system now tests binders at Minnesota temperatures (58C) rather than testing at temperatures Minnesota doesn't experience (64C). The asphalt binder PG 64 -XX will no longer be specified. This binder (PG 64 -xx) was used to "bump" up to a stiffer asphalt to minimize rutting and shoving potential on high ESAL and high volume roads with slow moving traffic. The asphalt binder grades now used with MSCR are PG 58x -28 and PG 58x -34. With MSCR grading the bumping is done through the selection of a letter after the high temperature grade (the 58x). The letter selection is S, H, V, and E (Standard, Heavy, Very Heavy, and Extremely Heavy traffic). As you move in that order from S to E the binder is still tested at 58C, but, has progressively more polymer and results in the bump previously used to achieve by selecting the PG 64. The "S" designation contains no polymer. As an example, where you previously specified PG 64 -28, you will now specify PG 58H -28.

Consider 2016 a transition year, very few projects will actually contain the new PG MSCR. This will be similar to when the change was made from Penetration grading to PG grading back in 1997. During the 2016 construction season liquid asphalt suppliers will still supply the asphalt grades specified in the contracts. Most projects won't need grade substitution but, if a supplier did want to substitute a MSCR grade for a conventional grade there should be no issue.

If you have questions please contact:

John Garrity, MnDOT Bituminous Engineer

Email: john.garrity@state.mn.us

Phone: (651)366-5577

Mao Yang

Email: mao.yang@state.mn.us

Phone: (651)366-3840

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MnDOT PG Binder Guidelines-MSCR

The new PG designations are different from the previous asphalt binder specification. Following AASHTO M332 (MSCR) the New PG grading designations for Minnesota will all be PG58, followed by traffic loading designation and minimum pavement design temperature. For example: PG58S-XX, PG58H-XX, PG58V-XX, and PG58E-XX.

S, H, V or E grade designations must be specified for standard, high, very high or extremely high traffic loading, respectively.

Type of Construction	Recommended Asphalt Binder for < 3 Million ESALs (20 yr)	Recommended Asphalt Binder for 3 - 10 Million ESALs (20 yr)	Recommended Asphalt Binder for > 10 Million ESALs (20 yr)
Overlay Wearing Mixture (Top 4'') ³	PG 58S-28	PG 58S-28 ¹	PG 58H-28 ¹
New Construction ² Wearing Mixture (Top 4'') ³	PG 58H-34	PG 58H-34 ¹	PG 58V-34 ¹
All Non-Wear Mixture (Below 4'' from Surface)	PG 58S-28		

Recommended Binder Grade for Shoulders:		
With Traffic	With No Traffic	Next to Concrete Mainline and Concrete Curb and Gutter
Generally, use the same binder grade as the mainline, but, not to exceed PG 58H-xx.	PG 58S-28 or PG 52S-34 (match the mainline low PG number)	PG 58S-28 or PG 58H-28

NOTES: When varying from these guidelines or for further clarification, consult the MnDOT Bituminous Office.

1. Selecting a higher PG grade and/or mixture type (traffic level), for higher ESALs within the category, will provide better resistance to rutting. Contact the Bituminous Engineer for guidance.
2. New construction includes: reconstruction, rubblization, CIR, reclaiming (FDR)
3. For Non-Trunk Highway with traffic levels <3 million ESAL, consider modifying the "top 4" criteria to top 3".
4. With concurrence of the Bituminous Office the designer may allow, by Special Provision, the Contractor's option to use PG 64S-22 on overlay construction when both of the following conditions are met:
 - a. Overlay thickness 3" or less and,
 - b. Average inplace crack/joint spacing 30ft. or less

The Special Provision shall limit the allowable RAP usage to 15% for mixtures specifying PG 64S-22.

Rules of Thumb

- Minimize the number of PG grades on any one project.
- The top 4” should be the same PG grade. Typically, specify PG xxx-34 for new construction. Typically, specify PG xxx-28 for overlay construction.
- Below 4” from the surface should be the same PG grade, typically, specify PG 58S-28.

Considerations

- For non-trunk highway with traffic levels < 3 million ESAL, consider modifying the top 4” criteria described under “Rules of Thumb” to top 3” criteria.
- For temporary construction (2 years or less) consider using PG 64S-22 when PG 58H-28 or PG 58V-34 is otherwise recommended.
- For special or unique design considerations contact the Bituminous Office.

Asphalt Binder Grade Designation

The PG Binder Grade letters should be used in all bituminous mixture designations, regardless of the specification number. These letters and PG Grade are listed below:

Binder Grades and Allowable Substitutions

A = PG 52S-34

B = PG 58S-28 allowed as substitute for PG 58-28

C = PG 58H-34 allowed as substitute for PG 58-34 & PG 58-34(PMB)

E = PG 58H-28 allowed as substitute for PG 64-28 & PG 64-28(PMB)

F = PG 58V-34 allowed as substitute for PG 64-34 & PG 64-34(PMB)

H = PG 58V-28 allowed as substitute for PG 70-28 & PG 70-28(PMB)

I = PG 58E-34 allowed as substitute for PG 70-34

L = PG 64S-22

M = PG 49S-34

Implementation of the Multi-Stress Creep Asphalt Binder Specification

This document is meant to give users of the asphalt binder specification answers to questions about this new specification and technology. Additionally it gives design and materials experts' guidance on use of asphalt binders when writing project proposals and documentation.

How are user agencies looking to implement the test/specification?

Beginning in 2015, MnDOT will begin making modifications to the MnDOT asphalt binder specification. Minnesota, along with the other states of the Combined State Binder Group, has decided to implement MSCR in 2 phases. The first phase, to be implemented in 2015, will use our current binder specification 3151 plus AASHTO M332 - MSCR Percent Recovery Test (R3.2). R3.2 verifies polymer modification in the asphalt binder. The second phase, to be implemented in 2016, will include R3.2 and non-recoverable creep compliance (J_{nr}), the non-recoverable shear strain/applied shear stress. Full implementation of the MSCR test will require us to re-designate our current asphalt binder grades and redo our PG Binder Guidelines, but, that change will not occur until 2016.

Why do we need a new high temperature parameter?

The present Superpave asphalt binder rutting resistance parameter $G^*/\sin \delta$ is based on complex modulus or stiffness and doesn't correlate well with field rutting measurements. That is because complex modulus is measured in the linear visco-elastic region and rutting is a non-linear failure. $G^*/\sin \delta$ has worked well with unmodified asphalt binder but doesn't characterize polymer-modified binders well. For unmodified asphalt binder, flow is linear and not effected by the stress level of the test. Polymer-modified asphalt binder response to stress levels is non-linear and is sensitive to stress levels much like rutting on our pavements. With MnDOT using more polymer-modified binders in recent years there was a need to develop a new high temperature performance grading test that correlates well with rutting for both neat and modified binders.

What is the new test?

The Multiple Stress Creep Recovery (MSCR) test is the latest improvement to the Superpave Performance Graded (PG) Asphalt Binder specification. This new test and specification – listed as AASHTO T350 and AASHTO M332 – provide the user with a new high temperature binder specification that more accurately indicates the rutting performance of the asphalt binder and is blind to binder modification. A major benefit of the new MSCR test is that it eliminates the need to run tests such as elastic recovery and phase angle procedures designed specifically to indicate polymer modification of asphalt binders. A single MSCR test can provide information on both performance and formulation of the asphalt binder. The MSCR test results allow binder formulators to use a more economic use of polymers to improve performance.

How does the MSCR test work?

The MSCR test uses the Dynamic Shear Rheometer (DSR) (Figure 1) to measure the non-recoverable creep compliance (J_{nr}) and percent recovery ($R_{3.2}$). The asphalt binder sample is sandwiched between the DSR's parallel plates and is sheared for one second and allowed to recover without loading for nine seconds. J (compliance) is inversely related to complex modulus. The lower the J_{nr} value the stiffer the binder. The permanent strain measured directly relates to rutting. The calculated J_{nr} is unrecoverable strain/ applied stress. The $R_{3.2}$ which gives us information about binder modification is recoverable strain/unrecoverable strain x 100%. Recovery tells us how readily the sample will return to its original

shape after being subjected to a load or stress. The slides in Figure 2 show how J_{nr} and Recovery are calculated from the MSCR test.

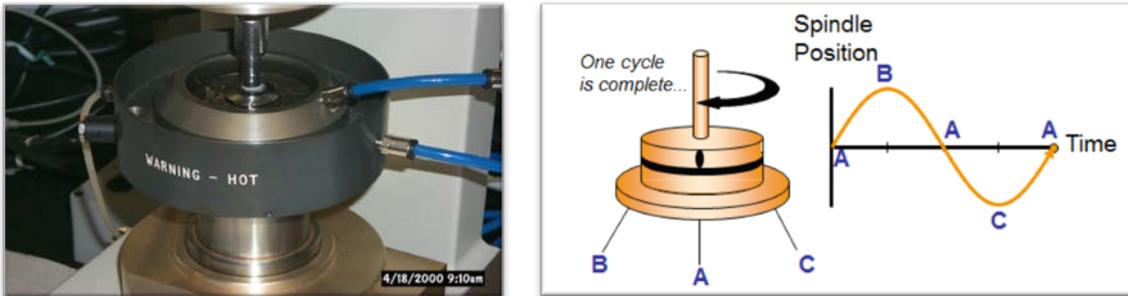


Figure 1: Dynamic Shear Rheometer

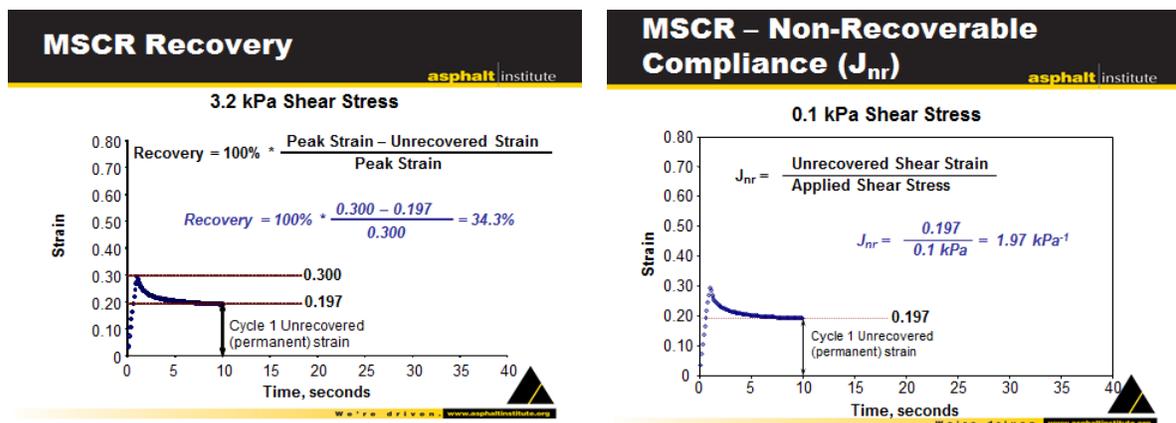


Figure 2: MSCR J_{nr} and R3.2
Slides used with permission from Asphalt Institute

How do MSCR results (J_{nr}) relate to rutting?

The relationship between J_{nr} and rutting has extensively been evaluated by full scale testing at FHWA's Accelerated Loading Facility (ALF) (Figure 3), Hamburg rut testing on MnROAD mixes and by a 6-year rutting study on Mississippi's I-55.

The ALF test sections included neat, air-blown, SBS-modified, GTR-modified and Elvaloy-modified binders. The sections were heated to 64°C and loaded with a 10,000 lb. super-single tire. Rutting of the test sections was compared to the existing PG high temperature parameter ($G^*/\sin \delta$) and also the MSCR high temperature parameter (J_{nr}). Figure 4 shows the correlation of high temperature binder tests with the FHWA Accelerated Loading Facility (ALF) at Turner Fairbanks Research Center and the poor relationship with the present binder specification.



Figure 3: FHWA Accelerated Loading Facility

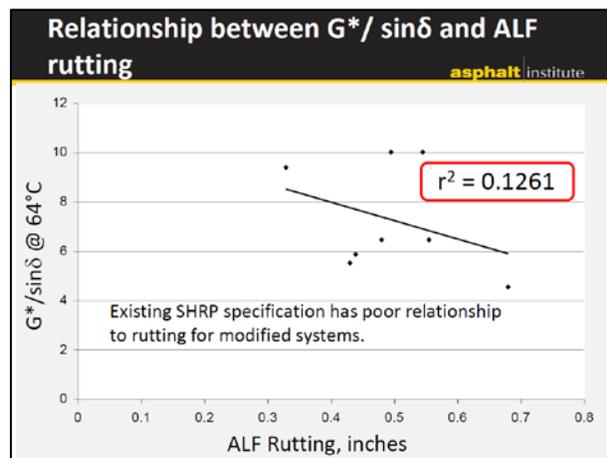
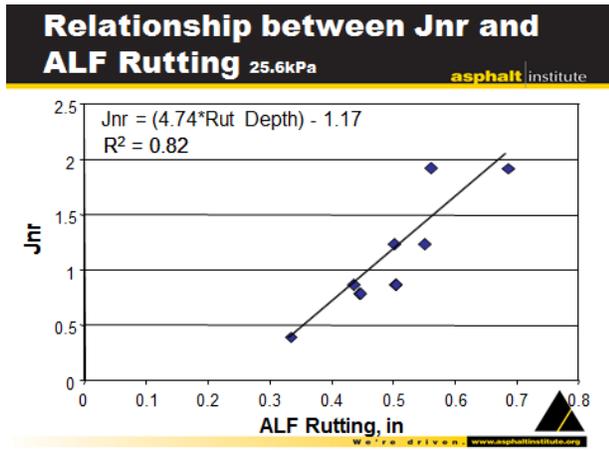


Figure 4: Relationship between Jnr and present binder specification and ALF Rutting

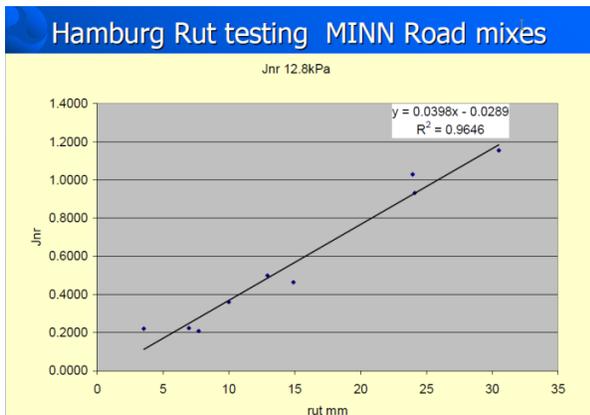


Figure 5- Hamburg Rut Testing on MnROAD Mixes

To evaluate HMA mixes used in Minnesota, Hamburg Rut testing was done on mixes from MnROAD PG58-28, PG 58-34 and PG 58-40 test sections (Figure 5). It can be seen that there is a very high correlation to Jnr results. To evaluate rutting on actual pavement, 6 years of rutting data was taken on Mississippi I-55 (Figure 6). Comparing the rutting data to Jnr gives a good correlation. Each of these evaluations show that Jnr is a much better test for rutting resistance than ($G^*/\sin \delta$) for all binders.

Mississippi I55: 6yr rutting J_{nr} 3.2 kPa

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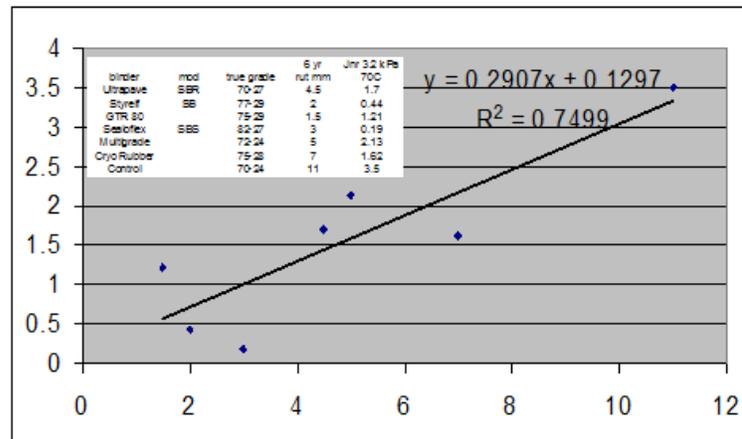


Figure 6-Mississippi I-55 6-Year Rutting

How does the specification work?

MnDOT and other states of the Combined State Binder Group will be using *AASHTO M 332- Standard Specification for Performance-Graded Asphalt Binder Using Multiple Stress Creep Recovery (MSCR) Test*. Implementation for using the full standard will take place in 2016. We will be using only the % Recovery portion of the specification in 2015. M332 states that this specification covers asphalt binders graded by performance using the multiple stress creep recovery (MSCR) test. Grading designations are related to the seven-day maximum pavement design temperature, minimum pavement design temperature, and traffic loading.

This specification incorporates AASHTO T 350 (MSCR Test) for determining non-recoverable creep compliance, J_{nr}. S, H, V or E grade designations must be specified for standard, high, very high or extremely high traffic loading, respectively. These grade designations are detailed below.

Standard Designation “S” in most typical situations will be for traffic levels fewer than 10 million Equivalent Single Axle Loads (ESALs) and more than the standard traffic speed (>70 km/h - 43.5mph).

High Designation “H” in most situations will be for traffic levels of 10 to 30 ESALs or slow moving traffic (12 to 44 mph).

Very High Designation “V” in most situations will be for traffic levels > 30 million ESALs or standing traffic (< 12mph)

Extremely High Designation “E” in most situations will be for traffic levels > 30 million ESALs or standing traffic (< 12mph) such as toll plazas and port facilities.

Table 1 shows the AASHTO M 332 specification for Minnesota.

TABLE 1: AASHTO M 332- Standard Specification for Performance-Graded Asphalt Binder Using Multiple Stress Creep Recovery (MSCR) Test.

MSCR, T 350, Standard Traffic "S" Grade Jnr 3.2, max 4.5 kPa-1 Jnr diff, max 75%, test temp, °C	58
MSCR, T 350, Heavy Traffic "H" Grade Jnr @ 3.2, max 2.0 kPa-1 Jnr diff, max 75%, test temp, °C	58
MSCR, T 350, Very Heavy Traffic "V" Grade Jnr @ 3.2, max 1.0 kPa-1 Jnr diff, max 75%, test temp, °C	58
MSCR, T350 Extremely Heavy Traffic "E" Grade Jnr @ 3.2, max 0.5 kPa-1 Jnr diff, max 75%, test temp, °C	58

A major difference between the new MSCR specification and the old Superpave high temperature spec is how grade bumping is done. In the old Superpave spec grade bumping was done by increasing the test temperature for the binder and keeping the required test results the same. Under the old system, if the standard grade is a PG58 based on climate and due to heavy traffic, and the agency wants 2 grade bumps they would specify a PG70. This required testing at 70°C for a 70-28 binder in a 58°C climate. In truth, the pavement will never see this high temperature; it is just an artificial way of requiring a stiffer binder by testing at a higher temperature. When using modified binders, this can provide some very misleading information. Grade bumping by increases in PG grade temp have forced suppliers to use very soft base binders and high degree of polymer modification to meet wide temperature ranges. This has made some polymers very stress sensitive. Many polymer systems soften very quickly at high temperatures. With the new MSCR specification, the binder testing is done at the high environmental temperature (58°C) that the pavement is expected to experience. If the climate grade is a PG58, you would do all high temperature testing at 58°C. If heavy traffic is expected the specification requirement is changed, i.e. a lower Jnr value is required to reflect the increased stress the pavement will actually experience, but testing is still done at say 58°C for a PG 58 climate. For example the MSCR spec for standard fast moving traffic Jnr requirement is 4.5 kPa-1 and for slow moving or higher traffic the required Jnr value would be 2.0 or 1.0 to require a more rut resistant material instead of testing at a higher temperature and high temperature testing for each S, H, V or E grades would be done at the same pavement climate temperature of 58°C. This allows for accurate evaluation of the binder at the expected operating temperature. Specification requirements for these examples can be seen by using Grade Designation definitions and Jnr requirements in Table 1 for those grades.

Table 2: Comparative Table between AASHTO M320 and M322

Present PG Grades- AASHTO M320	New MSCR Grades- AASHTO M332
PG 58-28	PG 58S-28
PG 64-28(PMB)	PG 58V-28
PG 70-28(PMB)	PG 58E-28
PG 58-34(PMB)	PG 58H-34
PG 64-34(PMB)	PG 58V-34

As stated above the new grade designation would in most cases have be PG 58 followed by the letter grade designation based on traffic levels followed by the low temperature grade. The low temperature grade will remain the same as always. An example is PG 64-28 will become PG 58V-28. Table 2 shows binder grades we presently use in Minnesota between the present grading system to the new MSCR grades that will be in effect in 2016. Only the MSCR % recovery will be used in 2015 projects. PG 49-34, PG64-22 and PG52-34 will be tested under AASHTO M320.

How can MSCR % Recovery be used and what does it indicate?

MSCR percent recovery is designated $R_{3.2}$ as it is measured at 3.2 KPa Shear Stress. The $R_{3.2}$ is recoverable strain/unrecoverable strain x 100%. $R_{3.2}$ tells us how readily the sample will return to its original shape after being subjected to a load or stress. The slide in Figure 2 show how $R_{3.2}$ are calculated from the MSCR test. Higher $R_{3.2}$ verifies the presence of polymers in the binder formulation. Figure 7 show the elastic response curve for PG 58-34 binders used in Minnesota in 2013. Binders with $R_{3.2}$ above black curve line indicate the presence of polymers and an elastic response to stress. As $R_{3.2}$ increases the polymer loading of the binder increases. The binders with $R_{3.2}$ in the orange circle with very low $R_{3.2}$ are either acid-modified or air-blown asphalts. It is clear that the $R_{3.2}$ test tells us information about binder formulation.

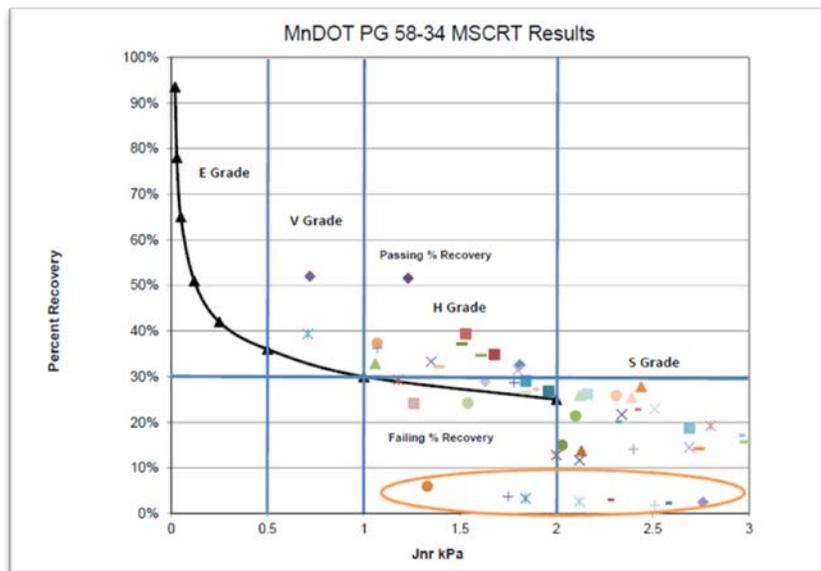
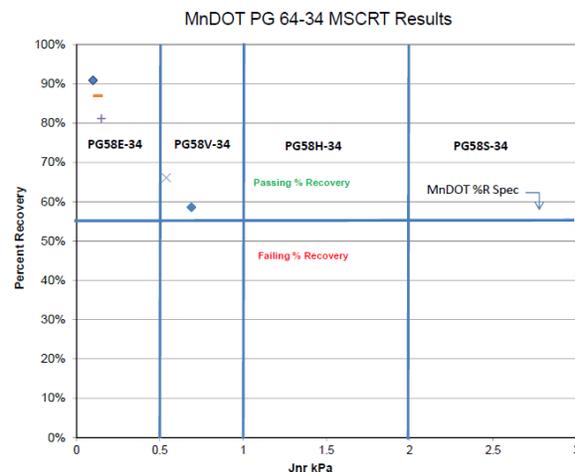
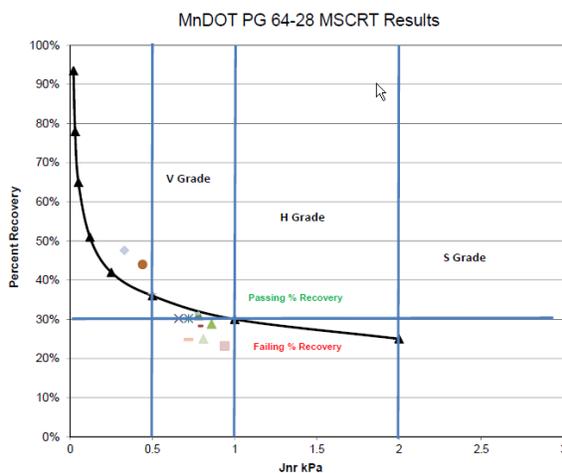


Figure 7: 2013 MnDOT PG 58-34 MSCRT Results

As stated earlier, in 2015 we will be using the present PG grading system (AASHTO M320) along with MSCR Percent Recovery ($R_{3,2}$) for polymer-modified binders. Table 3 lists the recovery requirements for polymer-modified binders. This test will assure design, materials and project engineers that polymer-modified binders will be supplied to their jobs when specified.

Table 3151.2A Percent Recovery ($R_{3,2}$)	
Asphalt Binder Grade	Minimum Percent Recovery*
PG 58-34 (PMB)	30%
PG 64-28 (PMB)	30%
PG 64-34 (PMB)	55%
PG 70-28 (PMB)	55%

With the present grade bumping system based on temperature, designers could be overly conservative in regards to rutting and require more polymer in our binders than necessary. The MnDOT Binder Lab ran MSCR tests on field samples submitted in 2013 and 2014. Looking at the charts for PG 64-28 and PG 64-34, we see that in both cases PG58V-xx would be specified but we have several binders tested that would fall into the PG 58E designation. The PG 58E designation would be equivalent to PG70-xx in our present system. Both specifiers and suppliers can use this test to assure the appropriate amount of polymer is used in binder formulations potentially resulting in decreased in binder costs.



What are the benefits of specifying polymer-modified asphalt binders?

For the 2015 construction season the new asphalt binder specification will require engineers to specify if a specific grade will be polymer modified or not. Some asphalt suppliers can provide a PG 58-34 and a PG 64-28 without polymer by adding polyphosphoric acid, by air blowing the asphalt, or by blending different crude asphalts together. Therefore, it is necessary to choose whether those grades are polymer modified. Besides helping with rutting resistance, there are other benefits to using polymer-modified binders. There is some proof that PMAC help with fatigue and thermal cracking resistance.

Harold Von Quintus et al conducted a study in 2005 to quantify the effects of Polymer-Modified Asphalt (PMA) used in Hot-Mix Asphalt. The research team conducted a survey of state agencies across the U.S. to get their expert opinion on PMA use and specifications. 70% of responses indicated better performance on PMA mixes when compared to conventional mixes. 58% stated that maintenance costs were less on PMA mixes. Those states estimated an extended service life of 4 to 6 yrs. The second part of the study was to compare the performance of PMA vs conventional mixes at 97 different sites across the United States and Canada using Long-Term Pavement Performance (LTPP), non-LTPP field test sections from various states and accelerated testing facilities such as NCAT and FHWA's Accelerated Loading Facility.

In the direct comparisons of conventional and PMA mixes, the PMA mixes showed smaller rutting, less fatigue cracking and fewer transverse cracks. Mechanical- Empirical (ME) pavement distress prediction models were used to quantify the improvement in pavement life and reduction in pavement distresses. Additionally it was determined that maintenance activities were reduced on PMA pavements. PMA performance is being significantly underestimated in the pavement design and selection process.

The report summary concluded the use of PMA mixtures result in less cracking and rutting – extending the service life of flexible pavements and overlays about half the cracking and about 40 percent of the rutting measured on comparison projects. PMA mixes provide a 25 percent or a 2- to 10-year increase in service life. [7]

The Colorado Asphalt Pavement Association (CAPA) requested that a similar study be conducted to confirm the effect of PMA in reducing pavement distress under Colorado's climate and truck traffic, and quantify the specific increase in service life for use in life cycle cost analyses. The overall objective of this study was to use the mechanistic-empirical (M-E) distress prediction models included in the Von Quintus study (Von Quintus, et al; 2004) to verify the reduction in pavement distress and quantify the increase in HMA overlay life when using modified mixtures in Colorado

The projects with modified mixtures within this study were found to have lower amounts of fatigue cracking, transverse cracking, and rutting, as compared to projects with neat HMA mixtures. Most of these projects were designed for 10 years. The use of modified HMA mixtures was found to extend the service life of HMA overlays by about 3 years – a 30 percent increase over the design life. This 3-year increase is conservative and was determined through the use of mechanistic-empirical (M-E) based distress prediction equations that were calibrated to Colorado conditions. The calibration factors used for the modified mixtures represent 75-percentil values. The 75-percentil values were used because of extrapolations and variability in the measured distress values. Use of 50-percentile values would have increased the three years to 5 to 6 years.

All of the projects with PMA mixtures were overlays of flexible or rigid pavements. As such, the increase in service life reported within this study for modified HMA overlays would be conservative for flexible pavements with modified mixtures. In other words, new construction projects that include PMA mixtures can be expected to have service lives in excess of three years longer than expected for neat HMA mixtures.

The specific increases in service life were found to be independent of region, traffic, and other site features typically encountered in Colorado. A bias was found between HMA overlays of flexible and rigid pavements bases. As a result, the determination of the service life for HMA overlays of flexible pavements should be considered separately from HMA overlays of rigid pavements. One reason for this bias is believed to be related to reflection cracks or joints from the underlying rigid pavement. [8]

While the benefits of using polymer- modified asphalts are widely acknowledged, not all asphalt mixes or treatments need to be modified. Each application should be evaluated to determine if the traffic loading, anticipated service life, environmental conditions and desired performance justify the use of modifiers. Modified asphalts can be a good investment.

References

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7. Von Quintus, H. L., J. Mallela, and J. Jiang. Quantification of the Effects of Polymer-Modified Asphalt for Reducing Pavement Distress. ER-215. Asphalt Institute, Lexington, Ky., 2004.
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• Additional MSCR Resources posted on AI's website–
<http://www.asphaltinstitute.org/public/engineering/mscr-information.dot>