# The relationships between asphalt mix rutting resistance and MSCR test results

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**ABSTRACT:** The asphalt mixtures rutting resistance depends on many factors connected to mineral composition and its characteristics, volume relationships, binder content and its properties. In the research program 15 samples of different binders were tested, 5 binders in stone matrix asphalt, 5 in asphalt concrete and 5 in high modulus asphalt concrete. The used binders were pure bituminous binder and PMBs with different amount of polymer. The binders' test program contained typical, conventional tests, as well as tests dedicated to Polymer Modified Binders. Finally, the three types of asphalt mixtures were tested at rutting test according EN 12697-22 specification. From the research it was concluded that there are a few relationships between specified binder properties and asphalt mixture characteristics. Among others the Multiple Stress Creep Recovery (MSCR) test results of samples tested at temperature related to rutting test temperature and viscosity are related to the rutting properties.

## INTRODUCTION

Rutting resistance is one of the most important property of well designed asphalt mixture. There are several factors which are connected to rutting resistance: mineral composition, type of used binder and volume relationships of designed asphalt mixture. While it is possible to predict rutting resistance according to asphalt mixture properties and volume relationships, it is not that simple with binder properties. Commonly used binder description seems to be insufficient. Authors presented results of $J_{nr}$ (non-recoverable creep compliance) acquired from Multiple Stress Creep Recovery test (MSCR) compared to penetration, softening point R&B and viscosity. Results of rutting resistance test (wheel tracking test) of 15 different asphalt mixtures were compared with properties of used binders.

## BINDERS

Evaluation was made for 15 laboratory made road binders of 3 different types:

- low penetration paving grade binders: P1, P6, P11.
- polymer modified binders with very low-to-low SBS polymer content: P2, P3, P7, P8, P12, P13.
- polymer modified binders with low-to-medium SBS polymer content: P4, P5, P9, P10, P14, P15.

Binders with high SBS polymer content were not used in the first stage of tests. Influence of SBS polymer content on rutting resistance was purpose of second stage of tests, which results are not presented in this publication.

Binders varied in penetration @25°C and purpose of usage:

- 5 hard grade binders (P1-P5) for High Modulus Asphalt Concrete (AC WMS 16 is similar to EME 16). Binders' properties are presented in table 1.
- 5 binders (P6-P10) for typical Asphalt Concrete used for binder layer (AC 16W). Binders' properties are presented in table 2.
- 5 binders (P11-P15) for Stone Matrix Asphalt used for surface layer (SMA 11). Binders' properties are presented in table 3.

**Table 1. Rutting resistance of High Modulus Asphalt Concrete and properties of used binders**

| Properties: | Binders for AC WMS 16: | | | | |
|---|---|---|---|---|---|
| | **P1** | **P2** | **P3** | **P4** | **P5** |
| Penetration @25°C [0,1 mm] | 30 | 32 | 36 | 34 | 40 |
| Softening Point R&B [°C] | 62.0 | 63.4 | 63.4 | 65.2 | 72.0 |
| Brookfield Viscosity @60°C [Pa*s] | 3 800 | 3 760 | 2 900 | 4 620 | 3 250 |
| Brookfield Viscosity @135°C [Pa*s] | 1.620 | 1.552 | 1.720 | 1.560 | 1.884 |
| ***MSCR at 64°C*** | | | | | |
| MSCR; $J_{nr}$@0.1 kPa, @64°C [$kPa^{-1}$] | 0.112 | 0.106 | 0.100 | 0.060 | 0.042 |
| MSCR; $J_{nr}$@3.2 kPa, @64°C [$kPa^{-1}$] | 0.117 | 0.109 | 0.113 | 0.078 | 0.077 |
| MSCR; $J_{nr}$diff, @64°C [%] | 4 | 3 | 13 | 30 | 83 |
| MSCR grading for traffic @64°C | extremely heavy | extremely heavy | extremely heavy | extremely heavy | not classified |
| ***MSCR at 70°C*** | | | | | |
| MSCR; $J_{nr}$@0.1 kPa, @70°C [$kPa^{-1}$] | 0.272 | 0.261 | 0.243 | 0.137 | 0.096 |
| MSCR; $J_{nr}$@3.2 kPa, @70°C [$kPa^{-1}$] | 0.311 | 0.301 | 0.303 | 0.245 | 0.242 |
| MSCR; $J_{nr}$diff, @70°C [%] | 14 | 15 | 25 | 79 | 152 |
| MSCR grading for traffic @70°C | extremely heavy | extremely heavy | extremely heavy | not classified | not classified |
| ***Asphalt mix rutting resistance*** | | | | | |
| Wheel Tracking Slope ($WTS_{AIR}$), h = 60 mm, 60°C, 10000 cycles, [mm/1000 cycles] (Note: requirement in national specification: max 0.15 mm/1000) | 0.08 | 0.08 | 0.05 | 0.03 | 0.02 |
| Proportional Rut Depth ($PRD_{AIR}$), h = 60 mm, 60°C, 10000 cycles, [%] | 6.6 | 6.9 | 5.2 | 3.6 | 2.4 |

For each binder following properties were tested:

- Penetration @25°C acc. to EN 1426,
- Softening Point Ring&Ball acc. to EN 1427,
- Brookfield Viscosity @60°C and 135°C acc. to ASTM D 4402
- MSCR with stress 0.1 kPa and 3.2 kPa, at temperatures: 64°C and 70°C acc. to ASTM D7405 - 10a, all binders after RTFOT.

Results of MSCR test were additionally evaluated for rutting resistance according to AASHTO MP 19-10 requirements, where binder grading for traffic based on $J_{nr}$@3.2 kPa and $J_{nr}$diff is presented.

**Table 2. Rutting resistance of Asphalt Concrete used for binder layer and properties of used binders**

| **Properties:** | **Binders for AC 16W:** | | | | |
|---|---|---|---|---|---|
| | **P6** | **P7** | **P8** | **P9** | **P10** |
| Penetration @25°C [0,1 mm] | 47 | 47 | 42 | 44 | 41 |
| Softening Point R&B [°C] | 54.0 | 57.2 | 60.4 | 62.8 | 64.0 |
| Brookfield Viscosity @60°C [Pa*s] | 806 | 1 220 | 1 520 | 2 180 | 3 150 |
| Brookfield Viscosity @135°C [Pa*s] | 0.787 | 0.946 | 1.124 | 1.366 | 1.512 |
| ***MSCR at 64°C*** | | | | | |
| MSCR; $J_{nr}$@0.1 kPa, @64°C [$kPa^{-1}$] | 0.533 | 0.388 | 0.145 | 0.074 | 0.048 |
| MSCR; $J_{nr}$@3.2 kPa, @64°C [$kPa^{-1}$] | 0.606 | 0.428 | 0.150 | 0.074 | 0.048 |
| MSCR; $J_{nr}$diff, @64°C [%] | 14 | 10 | 3 | 0 | 0 |
| MSCR grading for traffic @64°C | very heavy | extremely heavy | extremely heavy | extremely heavy | extremely heavy |
| ***MSCR at 70°C*** | | | | | |
| MSCR; $J_{nr}$@0.1 kPa, @70°C [$kPa^{-1}$] | 1.279 | 0.891 | 0.395 | 0.135 | 0.123 |
| MSCR; $J_{nr}$@3.2 kPa, @70°C [$kPa^{-1}$] | 1.553 | 1.073 | 0.416 | 0.158 | 0.143 |
| MSCR; $J_{nr}$diff, @70°C [%] | 21 | 20 | 5 | 17 | 16 |
| MSCR grading for traffic @70°C | heavy | heavy | extremely heavy | extremely heavy | extremely heavy |
| ***Asphalt mix rutting resistance*** | | | | | |
| Wheel Tracking Slope ($WTS_{AIR}$), h = 60 mm, 60°C, 10000 cycles, [mm/1000 cycles] (Note: requirement in national specification: max 0.15 mm/1000) | 0.08 | 0.07 | 0.06 | 0.03 | 0.02 |
| Proportional Rut Depth ($PRD_{AIR}$), h = 60 mm, 60°C, 10000 cycles, [%] | 7.1 | 6.5 | 5.4 | 4.1 | 2.6 |

**Table 3. Rutting resistance of Stone Matrix Asphalt used for surface layer and properties of used binders**

| Properties: | Binders for SMA 11: | | | | |
|---|---|---|---|---|---|
| | P11 | P12 | P13 | P14 | P15 |
| Penetration @25°C [0,1 mm] | 66 | 73 | 64 | 58 | 54 |
| Softening Point R&B [°C] | 50.0 | 52.0 | 52.4 | 56.8 | 59.0 |
| Brookfield Viscosity @60°C [Pa*s] | 332 | 384 | 480 | 570 | 714 |
| Brookfield Viscosity @135°C [Pa*s] | 0.532 | 0.580 | 0.672 | 0.805 | 1.008 |
| ***MSCR at 64°C*** | | | | | |
| MSCR; Jnr @0.1 kPa, @64°C [$kPa^{-1}$] | 0.933 | 0,810 | 0.403 | 0.179 | 0.117 |
| MSCR; Jnr @3.2 kPa, @64°C [$kPa^{-1}$] | 0.938 | 0,840 | 0.510 | 0.223 | 0.169 |
| MSCR; Jnr diff, @64°C [%] | 1 | 4 | 27 | 25 | 44 |
| MSCR grading for traffic @64°C | very heavy | very heavy | very heavy | extremely heavy | extremely heavy |
| ***MSCR at 70°C*** | | | | | |
| MSCR; Jnr @0.1 kPa, @70°C [$kPa^{-1}$] | 1.910 | 0.880 | 1.468 | 0.366 | 0.358 |
| MSCR; Jnr @3.2 kPa, @70°C [$kPa^{-1}$] | 1.819 | 1.152 | 1.568 | 0.536 | 0.481 |
| MSCR; Jnr diff, @70°C [%] | 5 | 31 | 7 | 46 | 34 |
| MSCR grading for traffic @70°C | heavy | heavy | heavy | very heavy | extremely heavy |
| ***Asphalt mix rutting resistance*** | | | | | |
| Wheel Tracking Slope ($WTS_{AIR}$), h = 40 mm, 60°C, 10000 cycles, [mm/1000 cycles] (Note: requirement in national specification: max 0.15 mm/1000) | 0.31 | 0.11 | 0.06 | 0.05 | 0.03 |
| Proportional Rut Depth ($PRD_{AIR}$), h = 40 mm, 60°C, 10000 cycles, [%] | 25.1 | 13.1 | 12.2 | 7.3 | 5.2 |

## ASPHALT MIXTURES

Following asphalt mixtures were made:

- AC WMS 16 high modulus asphalt concrete for binder and base layers according to EN 13108-1 standard,
- AC 16W asphalt concrete for binder layer according to EN 13108-1 standard,
- SMA 11 Stone Matrix Asphalt for surface layer according to EN 13108-5 standard.

Among each type of Asphalt Concrete and Stone Matrix Asphalt every mixture were prepared with the same mineral composition, with the same grading curves and the same binder content. Grading curve and properties of used asphalt mixtures are presented in table 4. Following properties were specified for the initial binder (the first binder specimen in each type of asphalt mixture).

**Table 4. Grading curves and properties for used asphalt mixtures**

| Properties: | AC WMS 16 (binder P1) | AC 16W (binder P6) | SMA 11 (binder P11) |
|---|---|---|---|
| Passing sieve # [mm] | | | |
| 22,4 | 100.0 | 100.0 | 100.0 |
| 16,0 | 98.2 | 97.7 | 100.0 |
| 11,2 | 86.8 | 83.3 | 96.6 |
| 8,0 | 74.7 | 69.3 | 64.0 |
| 5,0 | 57.8 | 54.6 | 36.4 |
| 2,0 | 33.5 | 30.3 | 23.7 |
| 0,125 | 12.1 | 9.9 | 12.7 |
| 0,063 | 8.9 | 7.2 | 10.2 |
| Binder content [% mass] | 5.0 | 4.6 | 6.6 |
| Density, $\rho_{mv}$ [Mg/m$^3$] | 2.495 | 2.511 | 2.439 |
| Bulk density, $\rho_b$ [Mg/m$^3$] | 2.397 | 2.397 | 2.359 |
| Void content $V_m$, [% vol.] | 3.9 | 4.5 | 3.2 |
| Voids filled with binder VFB, [%] | 75.1 | 70.4 | 82.5 |
| Voids in mineral aggregate VMA, [% vol.] | 15.7 | 15.4 | 18.5 |
| Complex Stiffness Modulus, 4PB-PR, t= 10°C, 10 Hz | 16446 | - | - |
| Fatigue resistance, 4PB-PR, t= 10°C, 10 Hz,<br>• Strain [μs]<br>• Number of cycles<br>• Fatigue damage [%] | <br>130<br>$10^6$<br>9.2 | - | - |

For each asphalt mixture wheel tracking test was conducted according to method B (air, 60°C) of EN 12697-22 standard. Rutting resistance was evaluated according to Proportional Rut Depth ($PRD_{AIR}$) and Wheel Tracking Slope ($WTS_{AIR}$). Tests were conducted with binder dedicated for one of three presented types of asphalt mixtures. Results of rutting resistance are presented in tables 1, 2 and 3.

## RESULTS & ANALYSIS

### Binder properties analysis

According to binders' tests results analysis, following statement can be made:

1. For every unmodified binder (P1, P6, P11) stress sensitivity factor $J_{nr}$diff remained on low level for the whole time of test and didn't exceed 75% value. Results confirmed good tolerance of unmodified binder for stress growth.
2. In specimens P4 and P5 there were visible problems with correct SBS modification of binder. Mentioned specimens had slightly higher softening point and better low-temperature properties. This type of binder modification presents risk of high susceptibility to stress growth. It was confirmed by results of MSCR test. In both binder specimens stress sensitivity factor $J_{nr}$diff exceeded 75% value. It was impossible to classify traffic for mentioned binder.

3. Non-recoverable stress compliance $J_{nr}$ ratio analysis for two level of stress and for two temperatures showed increase of $J_{nr}$ ratio with the increase of stress from 0.1 to 3.2 kPa. Increase of $J_{nr}$ ratio is also visible with the increase of both temperature. Similarly grading for traffic changed with the increase of both temperature and stress level.
4. In most cases recovery (R value) for $J_{nr}$3.2 property acquired in both temperatures (64 and 70°C) showed that the used method of binder modification is ineffective. The level of modification was too low.
5. Conventional tests allowed to evaluate binder specimens theoretically for better performance in asphalt mixtures, but weren't sufficient to clearly evaluate binder modification effectiveness.

Final evaluation of binder modification effectiveness will be made according to wheel tracking tests of asphalt mixtures.

**Asphalt mixtures rutting resistance analysis**

According to wheel tracking test results analysis, following statement can be made:
1. With the increase of binder modification rutting resistance also increased.
2. Asphalt concrete showed good rutting resistance. Regardless of the used binder, every asphalt concrete could be used for very high traffic according to Polish standard ($WTS_{AIR}$ @60°C max. 0.15 mm/1000 cycles)
3. Among stone matrix asphalt only mixtures with higher level of SBS polymer modification could be used for very high traffic. Initial SMA mixture with P11 binder (unmodified) wasn't sufficient even to heavy traffic. One should note that for binders used for AC mixtures samples were rather hard. Meanwhile binders used for SMA mixtures samples were at least one grade softer.

According to MSCR tests results, P4 and P5 binders' properties were unsatisfactory. On the contrary in the wheel tracking test they didn't show this behavior. On the other hand comparison of P11 (the worst result in MSCR test) and P13 binder, which were classified to the same traffic grading in both temperatures (very heavy in temperature 64°C and heavy in 70°C), shows different behavior. P13 showed good behavior in wheel tracking test, while P11 binder didn't even reach designed ratio ($WTS_{AIR}$ was higher than 0.15 mm/1000 cycles). It shows that the results of binders test alone isn't sufficient to evaluate the impact of used binder for asphalt mixture properties, especially when type of binder modification is taken under consideration.

**Relationships between binder properties and wheel tracking test results**

The next stage in results analysis was finding relationships between binder properties and wheel tracking test results. Analysis involved determining $R^2$ determination coefficient between binder properties and $WTS_{AIR}$ and $PRD_{AIR}$ values for each used asphalt mixture. Especially $R^2$ determination coefficient between MSCR $J_{nr}$ results and $WTS_{AIR}$ and $PRD_{AIR}$ results were investigated thoroughly. Calculated $R^2$coefficients are presented in tables 5 and 6

**Table 5. Relationships between binder properties and proportional rut depth $PRD_{AIR}$**

| Properties: | $PRD_{AIR}$ $R^2$ determination coefficient | | |
|---|---|---|---|
| | AC WMS16 | AC 16W | SMA 11 |
| Penetration @25°C [0,1 mm] | 0.7239 | 0.7109 | 0.3533 |
| Softening Point R&B [°C] | 0.7525 | 0.9099 | 0.7872 |
| Brookfield Viscosity @60°C [Pa*s] | 0.000008 | 0.9835 | 0.7590 |
| Brookfield Viscosity @135°C [Pa*s] | 0.4248 | 0.9794 | 0.7031 |
| MSCR; Jnr @0.1 kPa, @64°C [$kPa^{-1}$] | 0.9390 | 0.8270 | 0.7921 |
| MSCR; Jnr @3.2 kPa, @64°C [$kPa^{-1}$] | 0.8164 | 0.8140 | 0.7833 |
| MSCR; Jnr diff, @64°C [%] | 0.8340 | 0.8265 | 0.6745 |
| MSCR; Jnr @0.1 kPa, @70°C [$kPa^{-1}$] | 0.9422 | 0.8326 | 0.8239 |
| MSCR; Jnr @3.2 kPa, @70°C [$kPa^{-1}$] | 0.8541 | 0.8113 | 0.7799 |
| MSCR; Jnr diff, @70°C [%] | 0.8867 | 0.9822* | 0.5687 |

* - one outlier value was discarded

**Table 6. Relationships between binder properties and wheel tracking slope $WTS_{AIR}$**

| Properties: | $WTS_{AIR}$ $R^2$ determination coefficient | | |
|---|---|---|---|
| | AC WMS16 | AC 16W | SMA 11 |
| Penetration @25°C [0,1 mm] | 0.7267 | 0.5757 | 0.2174 |
| Softening Point R&B [°C] | 0.6462 | 0.9081 | 0.5710 |
| Brookfield Viscosity @60°C [Pa*s] | 0.00001 | 0.9396 | 0.5968 |
| Brookfield Viscosity @135°C [Pa*s] | 0.3604 | 0.9791 | 0.5185 |
| MSCR; Jnr @0.1 kPa, @64°C [$kPa^{-1}$] | 0.8821 | 0.8159 | 0.7035 |
| MSCR; Jnr @3.2 kPa, @64°C [$kPa^{-1}$] | 0.7764 | 0.8031 | 0.6591 |
| MSCR; Jnr diff, @64°C [%] | 0.7229 | 0.8326 | 0.6107 |
| MSCR; Jnr @0.1 kPa, @70°C [$kPa^{-1}$] | 0.8874 | 0.8422 | 0.6250 |
| MSCR; Jnr @3.2 kPa, @70°C [$kPa^{-1}$] | 0.8141 | 0.8137 | 0.5490 |
| MSCR; Jnr diff, @70°C [%] | 0.7828 | 0.9977* | 0.3832 |

* - one outlier value was discarded

## CONCLUSIONS

According to analysis, following statements can be made:

1. Generally, relationships between binder properties and rutting resistance were better for asphalt concretes (both conventional and high modulus asphalt concretes).
2. The best correlations were acquired for conventional AC 16W asphalt concrete. Both MSCR test results as well as conventional binder tests results showed very high correlations (above 0.8).

3. AC WMS 16 high modulus asphalt concrete showed high correlations between MSCR test results and rutting resistance. Surprisingly there weren't any correlations between Brookfield Viscosity test results and rutting resistance. Very high viscosity and rather small differences in viscosity between evaluated binders could be the possible cause of this phenomena.
4. The worse correlations were acquired for SMA 11. Higher influence of the SMA's aggregate skeleton (i.e. better stone-to-stone contact) on rutting resistance might be the main cause. Therefore correlations between both MSCR and conventional binder test results and rutting resistance are not evident.

Correlations between rutting resistance and both MSCR and conventional binder tests result depended highly on type of used asphalt mixture. Properties of binder have lower impact on SMAs' rutting resistance and almost all calculated coefficients are lower than for AC. AC mixtures are more sensitive to properties of used binder thus better correlations between rutting and binder tests are observed.

Conducted tests showed that preliminary evaluation of rutting resistance of asphalt mixtures could be done with binder tests results, however one should remember that MSCR results aren't an universal indicator of hot-mix rutting resistance because this matter depends on type of used aggregate mixture. As usually, final evaluation should be made using asphalt mixture rutting resistance tests. Asphalt mixture tests results give better assessment of the full scale behavior. Evaluation of binder tests results alone weren't sufficient for assessment of specific types of asphalt mixtures, especially for Stone Matrix Asphalt. MSCR test results showed very high $R^2$ determination coefficients for typical asphalt concrete, while for high modulus asphalt concrete $R^2$ determination coefficients were slightly lower. Stone Matrix Asphalt showed the worse $R^2$ determination coefficients between binder test results and wheel tracking test results.

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