Practical experiences with new types of highly modified asphalt binders

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Abstract. As a result of steadily increasing traffic load on the roads in the Czech Republic, we should be focused on the innovative technical solutions, which will lead to extending the life time of asphalt pavements. One of these ways could be the future use of bitumen with a higher degree of polymer modification. This paper discusses experience with comparison of new highly polymer modified asphalt binder type with conventional polymer modified asphalt binder and unmodified binder with penetration grade 50/70. There are compared the results of various types laboratory tests of asphalt binders, as well as the results of asphalt mixtures laboratory tests. The paper also mentions the experience with workability and compactability of asphalt mixture with highly polymer modified asphalt binder during the realization of the experimental reference road section by the Skanska company in the Czech Republic.

1. Introduction

In these days, there are a lot of challenges in the field of asphalt technologies like increasing traffic load and higher requirements on durability of asphalt pavements. One of the options to face these challenges could be usage of highly polymer modified asphalt binders [19], [20], [21], [22].

For practical evaluation of asphalt mixtures with highly polymer modified asphalt binder just in real pavement there was carried out experimental road section by Skanska company in 2016. Before the realization of experimental road section there were performed laboratory comparisons of highly polymer modified asphalt binder with conventional PmB and paving grade bitumen 50/70. There were also carried out various laboratory tests of asphalt mixture for friction courses ACO 11 S with all above mentioned types of asphalt binders.

The experimental road section made of friction course ACO 11 S with highly polymer modified asphalt binder by TOTAL company (PmB 25/55-75 Styrelf) was carried out by Sknaska company in October 2016. This experimental road section is placed in logistical complex, where high point loads and high radial forces from heavy trucks and forklifts are expected.

This research study consists of three basic parts:

1) Testing of three different asphalt binders properties (paving grade bitumen 50/70, conventional PmB 25/55-65, highly polymer modified PmB 25/55-75).
2) Testing of asphalt mixture properties with three above mentioned compared types of asphalt binders.
3) Experimental road section paving and evaluation.
2. Input materials
Into the asphalt mixture for experimental road section, there were used below mentioned input materials:

- highly polymer modified asphalt binder STYREL PmB 25/55-75 from TOTAL;
- mineral aggregate from Zarubka quarry fraction 0/4, 4/8, 8/11;
- limestone mineral filer from Prachovice.

The geological type of used mineral aggregate from Zarubka quarry is Granodiorite. All used mineral aggregate was in accordance with technical requirements according to technical standard ČSN EN 13108-1 [12] for mineral aggregate into the friction courses.

3. Asphalt binder STYREL PmB 25/55-75 production
The highly polymer modified asphalt binder was produced in two steps. The first phase consisted of the blending of a granulated linear SBS polymer into a purely distilled bitumen with the help of an IKA shear mill in a TOTAL BITUMEN DEUTSCHLAND refinery. This concentrate has been chemically cross-linked and additivated with a scavenger to reduce the hydrogen sulfide concentrations in the gas phase of the dead space of the tanks, in which the bitumen is transported and stored.

This concentrate was shipped into the bitumen depot belonging to TOTAL ČESKÁ REPUBLIKA s.r.o. in Kouřim where it was blended with other bitumen through the INDAG DLM/S in-line mixer to produce a highly polymer modified asphalt binder with a penetration range of 25 – 55 and a softening point higher than 75 °C.

The bitumen was produced directly into the tanker truck and has not been intermediately stored. During the production process another additive was added to the binder in order to improve the adhesion, reduce the ageing sensitivity and thus increase the lifespan of the pavement. Sampling has been done during the loading – from the main stream pipe with a Strahman piston sampling valve – according to technical standard ČSN EN 58 – Sampling bituminous binders.

No complications were observed during the loading process – the temperature during production was approx. 176 °C and the loading time was close to 35 minutes.

4. Asphalt binder laboratory testing results
The asphalt mixture ACO 11 S used for the experimental road section was produced with a highly polymer modified asphalt binder PmB 25/55-75. To further analyze the binder properties a series of laboratory tests was performed. In order to have a comparison to these results, other conventional bitumen have been tested as well – the set consists of paving grade bitumen Azalt 50/70 and polymer modified bitumen Styrel PmB 25/55-65. All bitumen were supplied by TOTAL. The set of tests was repeated for all binder also after various ageing methods:

1) RTFOT (Short term ageing – Rolling thin film oven test) [10]
2) RTFOT + PAV (Pressure ageing vessel – Long term ageing test) [10], [11]
3) 3 x RTFOT

The results of all tests performed on the binders are presented in Tables 1, 2, 3 and 4.
Table 1. Selected performance properties of the un-aged binders.

| Property                     | Unit       | 50/70 | PmB 25/55-65 | PmB 25/55-75 |
|------------------------------|------------|-------|--------------|--------------|
| Virgin binder                |            |       |              |              |
| Penetration [4]              | [0.1mm]    | 63    | 35           | 42           |
| Softening point [5]          | [°C]       | 47.7  | 69.6         | 77           |
| Fraass breaking point [8]    | [°C]       | -10   | -13          | -18          |
| Flash point [9]              | [°C]       | 317   | 336          | 341          |
| Elastic recovery @ 25°C [6]  | [%]        | -     | 70           | 88           |
| Force ductility @ 10°C [7]   | [J/cm²]    | -     | 4            | 5.7          |

Table 2. Selected performance properties of the RFFOT aged binders.

| Property                     | Unit       | 50/70 | PmB 25/55-65 | PmB 25/55-75 |
|------------------------------|------------|-------|--------------|--------------|
| RFOT Aged binder [10]        |            |       |              |              |
| Retained penetration [4]     | [%]        | 75    | 89           | 93           |
| Increase in softening point [5]| [°C]     | 5     | 8.4          | 8.5          |
| Change of mass               | [%]        | 0     | 0.1          | 0.1          |
| Penetration [4]              | [0.1mm]    | 47    | 31           | 39           |
| Softening point [5]          | [°C]       | 52.4  | 78           | 85.5         |
| Elastic recovery @ 25°C [6]  | [°C]       | -     | 64           | 83           |
| Force ductility @ 10°C [7]   | [J/cm²]    | -     | 1            | 1.3          |
| Recovery MSCR 0.1kPa         | [%]        | 3.19  | 78.56        | 90.98        |
| Non-recoverable creep        | [1/kPa]    | 2.11  | 0.03         | 0.02         |
| compliance MSCR 0.1 kPa      |            |       |              |              |
| Recovery MSCR 3.2kPa         | [%]        | 1.23  | 77.92        | 90.91        |
| Non-recoverable creep        | [1/kPa]    | 2.14  | 0.03         | 0.02         |
| compliance MSCR 3.2 kPa      |            |       |              |              |
| R_{diff}                     | [%]        | 61.446| 0.812        | 0.073        |
| J_{nr-diff}                  | [%]        | 1.557 | 4.422        | 1.429        |

A clear difference between the properties of the paving grade bitumen and the polymer modified bitumen can be seen from the results. The modified asphalt binders outperform the paving grade bitumen in all followed parameters.

Based on the fact that the real deal in binder performance is its behaviour in the asphalt mixture, it can be said – based on the differences in the empirical properties, but mainly the functional MSCR (Multiple Stress Creep Recovery) and the DSR (Dynamic Shear Rheometer) phase angle differences – that both polymer modified asphalt binders show a greater resistance to rutting in comparison with the paving grade bitumen.

The properties of all three binders were in accordance with the technical standard ČSN EN 12591 [2] for paving grade bitumen and technical standard ČSN EN 14023 [3] for polymer modified bitumen, although it should be fairly concluded that the demands of these technical standards are in the Czech Republic quite low. An interesting difference can be seen in the adhesion of the binders where both modified asphalt binders showed better results than the paving grade bitumen. Thanks to this fact and in combination with a relatively high deformation energy – reaching almost 200% of the
technical standard demand for the gradation PmB 25/55 – 75 – good adhesion and cohesion properties of the highly polymer modified binder can be expected in the asphalt mixture.

If we compare only the modified asphalt binders which were tested, a difference in the softening point can be seen, which was due to the nature of the test only limited informative potential about the binder performance. Another difference is the Fraass breaking point temperature, which would point to a higher modification of the PmB 25/55-75 binder.

| Table 3. Selected performance properties of the RTFOT + PAV aged binders. |
|-----------------------------------------------|----------------|----------------|
| Property                                    | Unit          | 50/70          | PmB 25/55-65 | PmB 25/55-75 |
| Penetration [4]                             | [0,1mm]       | 20             | 22           | 29           |
| Softening point [5]                         | [°C]          | 65.8           | 86.5         | 89           |
| Elastic recovery @ 25°C [6]                 | [°C]          | -              | 50           | 77           |
| Force ductility @ 10°C [7]                  | [J/cm²]       | -              | -            | 2.5          |
| Recovery MSCR 0.1kPa                        | [%]           | 21.72          | 82.64        | 91.4         |
| Non-recoverable creep compliance MSCR 0.1 kPa | [1/kPa]    | 0.17           | 0.01         | 0.01         |
| Recovery MSCR 3.2kPa                        | [%]           | 19.75          | 82.85        | 91.37        |
| Non-recoverable creep compliance MSCR 3.2 kPa | [1/kPa]    | 0.17           | 0.01         | 0.01         |
| $R_{diff}$                                  | [%]           | 9.063          | -0.256       | 0.031        |
| $J_{nr-diff}$                               | [%]           | 1.557          | -2.271       | -1.858       |

| Table 4. Selected performance properties of the RTFOT + PAV aged binders. |
|-----------------------------------------------|----------------|----------------|
| Property                                    | Unit          | 50/70          | PmB 25/55-65 | PmB 25/55-75 |
| Penetration [4]                             | [0,1mm]       | 30             | 26           | 25           |
| Softening point [5]                         | [°C]          | 58.8           | 87           | 91.5         |
| Change of mass [%]                          |               | 0.1            | 0.1          | 0.1          |
| Elastic recovery @ 25°C [6]                 | [°C]          | -              | 59           | 72           |
| Force ductility @ 10°C [7]                  | [J/cm²]       | -              | 1.4          | 2.2          |
| Recovery MSCR 0.1kPa                        | [%]           | 10.68          | 83           | 92.62        |
| Non-recoverable creep compliance MSCR 0.1 kPa | [1/kPa]    | 0.62           | 0.01         | 0.01         |
| Recovery MSCR 3.2kPa                        | [%]           | 7.45           | 83.67        | 92.68        |
| Non-recoverable creep compliance MSCR 3.2 kPa | [1/kPa]    | 0.63           | 0.01         | 0.01         |
| $R_{diff}$                                  | [%]           | 30.181         | -0.817       | -0.068       |
| $J_{nr-diff}$                               | [%]           | 1.804          | -4.093       | 0.253        |

Difference can be seen in the force ductility and elastic recovery on the virgin binder and the recovery of the MSCR test on the RTFOT aged binder – which shows the higher level of polymer modification of the PmB 25/55-75 binder. These results show the higher resistance of the PmB 25/55-75 binder against fatigue cracking and low temperature cracking. Due to the fact, that the asphalt
mixture has to withstand mainly local static load and stresses caused by forklifts, a better resistance against rutting can be expected in the long term [1].

From the results it can be concluded that the paving grade bitumen 50/70 and the polymer modified asphalt binders react differently to different ageing methods and thus it is difficult to draw clear conclusions from the above mentioned test results. It is recommended to pay attention to this fact in the future research due to the increase number of binder properties that have to be measured after RTFOT + PAV according to new asphalt binder technical standards.

If we focus on the ageing test methods used in the EN technical standards for polymer modified bitumen – RTFOT + PAV – we can see that the paving grade bitumen undergoes a greater ageing change. To further conclude – if we would follow only the results of the binder testing in this paper – the higher polymer modification improves the ageing resistance and also the lifespan of the pavement. These results are in line with the currently longest ageing research on asphalt binder ageing in the pavement – which has been done as part of the LAVOC (Le Laboratoire des voies de circulation) study [19] in the years 1988 – 2007 – and that shows certain limits in the ageing of highly polymer modified asphalt binders, after which there are no further changes in the colloidal composition of the bitumen and thus no further performance changes.

During the elastic recovery and force ductility test of the PmB 25/55-65, the test sample broke before reaching the test length, while the samples of the highly polymer modified asphalt binder PmB 25/55-75 stayed intact.

Differences can be seen in the recovery of the binders, while the DSR phase angle show almost the same values.

All results point of the fact, that the PmB 25/55-75 binder has a greater resistance against ageing in comparison with standard polymer modified asphalt binder PmB 25/55-65 and paving grade bitumen 50/70 [1].

5. Production of asphalt mixture ACO 11 S PmB 25/55-75
The asphalt mixture was produced in the asphalt mixing plant Teltomat V in Polička - Modřec. The temperature of the asphalt mixture during production ranged from 175 to 185°C. Subsequently, the mixture was dispatched from the container of hot asphalt mixture to trucks and delivered to about 25 km distant construction site, where the realization of the experimental road section took place. Due to the transport distance and routing mainly on the first class road, the transport time from mixing plant to the place of laying asphalt mixtures does not exceed 45 minutes.

To verify physical-mechanical and functional properties of the asphalt mixtures sampled from the production in the mixing plant, a number of control laboratory tests was performed. The tests were performed both for the mixture ACO 11 S with highly polymer modified asphalt binder PmB 25/55-75, and for a conventional mix ACO 11 S with unmodified road bitumen 50/70 as well as for the mixture ACO 11 S with conventional polymer modified asphalt binder PmB 25/55-65. Afterward, properties of these mixtures were compared and the results are given in the following chapter [1].

6. Results of laboratory tests of asphalt mixtures

6.1. Comparison of basic asphalt mixtures properties
The properties of the mixture ACO 11 S PmB 25/55-75, which was used for realization of the experimental road section, were compared with the properties of conventional mixtures ACO 11 S 50/70 and mixtures ACO 11 S PmB 25/55-65. All these mixtures have the same gradation curve, only difference is the asphalt binder and the temperature at which the mixtures were compacted. A mixture with modified asphalt binder requires higher temperature during compaction, specifically 155°C compared to 150°C for a mixture with conventional paving grade bitumen 50/70. This results in achieving different values of bulk density and consequently porosity. Specific values measured in control tests are shown in Table 5 [1].
Table 5. Comparison of the basic properties of asphalt mixtures ACO 11 S with different types of bituminous binders.

| Mixture: | ACO 11 S PmB 25/55-75 | ACO 11 S PmB 25/55-65 | ACO 11 S 50/70 |
|----------|-----------------------|-----------------------|----------------|
| Maximal specific gravity $\rho_{mv}$ (Mg.m$^{-3}$) [14] | 2.465 | 2.452 | 2.444 |
| Bulk specific gravity $\rho_{bssd}$ (Mg.m$^{-3}$) [13] | 2.393 | 2.382 | 2.370 |
| Air voids content $V_m$ (% of volume) [15] | 2.9 | 2.9 | 3.0 |

6.2. Determination of asphalt mixture resistance against the water damage

A set of six specimens was prepared in the Marshall compactor for the asphalt mixture ACO 11 S PmB 25/55-75, a comparative mixture ACO 11 S 50/70 and mixture ACO 11 S PmB 25/55-65. Compacting was done by 2 x 25 hits of Marshall compactor at 155°C for the mixtures with the polymer modified asphalt binder and 2 x 25 hits of Marshall compactor at 150°C for the conventional mix ACO 11 S with unmodified paving grade binder 50/70. Resistance to water was subsequently tested according to the standard ČSN EN 12 697 – 12 on these compacted test specimens. Results of the tests are shown in Table 6 [1].

Table 6. The test results ITSR [16].

| Mixture: | ACO 11 S PmB 25/55-75 | ACO 11 S PmB 25/55-65 | ACO 11 S 50/70 |
|----------|-----------------------|-----------------------|----------------|
| Ø indirect tensile strength (wet group) [kPa] | 885 | 1010 | 830 |
| Ø indirect tensile strength (dry group) [kPa] | 1040 | 1050 | 920 |
| ITSR [%] | 85.1 | 96.2 | 90.2 |

The lowest value of ITSR was measured for the specimens prepared from a mixture of ACO 11 S PmB 25/55-75. However, the indirect tensile strength of the group of dry specimens is comparable with the mixture ACO 11 S PmB 25/55-65. The results show that although ITSR value is higher for the mixture ACO 11 S 50/70 than the mixture ACO 11 S PmB 25/55-75, indirect tensile strength of the mixture ACO 11 S PmB 25/55-75 has significantly higher values in both dry and wet groups of specimens. The values of ITSR of all tested mixtures fulfilled the requirement of ČSN EN 13 108-1 - not less than 80%. The surprising lowest value of ITSR, determined for the mixture ACO 11 S PmB 25/55-75, could be partly influenced by production inaccuracies in the asphalt mixing plant. For a more precise determination of the ITSR parameter, it would be appropriate to repeat the test on laboratory prepared mixtures.

6.3. Wheel tracking test

The mixture ACO 11 S PmB 25/55-75 was also tested to wheel tracking (resistance to permanent deformation). Comparative mixture ACO 11 S 50/70 and the mixture ACO 11 S PmB 25/55-65 also underwent this test. Test plates with thickness of 40 mm, compacted at 99.0 to 100.0%, were laboratory prepared from each mixture. Bulk density of the specimen prepared within the control analysis of mixtures was used as a reference value. The compaction temperature of the test specimens was 155°C for mixtures with polymer modified asphalt binder and 150°C for mixture with conventional road bitumen 50/70. Testing temperature was 50°C and the results of the test are shown in Table 7 [1].
Table 7. Results of rutting test (50 °C) [17].

| Mixture:          | Rutting PRD$_{\text{AIR}}$ [%] | Rutting WTS$_{\text{AIR}}$ [mm/10$^3$ cyklů] |
|-------------------|---------------------------------|-----------------------------------------------|
| ACO 11 S 50/70    | 2.6                             | 0.021                                         |
| ACO 11 S PmB 25/55-65 | 2.4                             | 0.010                                         |
| ACO 11 S PmB 25/55-75 | 2.3                             | 0.023                                         |

The results of the test determining resistance of asphalt mixtures to permanent deformation performed at 50°C do not indicate any large differences. In regard to the experience that the surface temperature of surface course may reach temperature exceeding 50°C on hot summer days, the test of resistance to permanent deformation was also performed at 60°C and the results of this test are shown in Table 8.

Table 8. Results of rutting test (60 °C) [17].

| Mixture:          | Rutting PRD$_{\text{AIR}}$ [%] | Rutting WTS$_{\text{AIR}}$ [mm/10$^3$ cyklů] |
|-------------------|---------------------------------|-----------------------------------------------|
| ACO 11 S 50/70    | 5.6                             | 0.105                                         |
| ACO 11 S PmB 25/55-65 | 3.5                             | 0.051                                         |
| ACO 11 S PmB 25/55-75 | 3.0                             | 0.036                                         |

![Figure 1. Results of rutting test – Proportional Rut Depth (60 °C) [17].](image)
Results of tests of asphalt mixture resistance to permanent deformation performed at 60°C clearly show how the type of asphalt binder influences the resistance against the permanent deformation. This is significant especially for surface courses which are directly confronted with high temperatures in summer.

6.4. Low-temperature properties and crack formation by using uniaxial tensile test
Finally, mixtures ACO 11 S PmB 25/55-75 and comparative mixture ACO 11 S PmB 25/55-65 were underwent to low-temperature properties test and crack formation by using uniaxial tensile test. Three specimens of dimensions 50 x 50 x 200 mm for each of the mixtures were prepared and tested for this test. The test results are summarized in Table 9 [1].

| Mixture: ACO 11 S PmB 25/55-65 | ACO 11 S PmB 25/55-75 |
|--------------------------------|-----------------------|
| sample                        | 1  | 2  | 3  | 1  | 2  | 3  |
| The temperature in the chamber | -21.7 | -23.8 | -24.1 | -25.0 | -25.6 | -25.4 |
| at failure [°C]               |     |     |     |     |     |     |
| The temperature of the sample | -17.3 | -20.3 | -20.5 | -21.5 | -21.3 | -21.4 |
| at failure [°C]               |     |     |     |     |     |     |
| The average temperature of the | -19.3 |     |     |     |     | -21.4 |
| samples at failure [°C]       |     |     |     |     |     |     |

It is apparent from the test results of low-temperature properties of asphalt mixtures ACO 11 S PmB 25/55-65 and ACO 11 S PmB 25/55-75 that the asphalt mixture with highly polymer modified asphalt binder is less susceptible to the formation of low temperature cracks. Generally, it can be concluded from the laboratory tests mentioned above that the mixture with highly polymer modified asphalt binder achieves better parameters in tests running at high temperatures, as well as low temperatures.
7. Paving of asphalt mixture ACO 11 S PmB 25/55-75

Paving and compacting of asphalt mixture ACO 11 S PmB 25/55-75 was performed by the following machinery in the thickness of 40 mm:

- Asphalt Paver 1803-3i Vögele
- Compaction roller HAM HD 90
- Compaction roller HAM HD 12

During the paving, workability and compactability of the mixtures were mainly monitored. During the machine paving, no differences were observed compared to the machine paving of conventional asphalt mixture ACO 11 S with paving grade bitumen 50/70, or the polymer modified asphalt binder PmB 25/55-65. However, noticeable difference was observed during hand paving in places where machine paving was not possible. Already at temperatures around 160°C, the mixture exhibited a high degree of consistency and it was difficult to work with. The degree of compaction of the asphalt layer was checked by laboratory staff of company Skanska Asfalt s.r.o. using nondestructive nuclear gauge Troxler 4640B. The measurement was made after each pass of roller [1].

Table 10. The results measure the degree of compaction by radiosonde Troxler.

| Bulk specific gravity | Rate of compaction [%] | Air voids content in layer [%] |
|-----------------------|------------------------|-------------------------------|
| 1. compaction cycle   | 2.271                  | 94.9                         | 7.9                          |
| 2. compaction cycle   | 2.329                  | 97.3                         | 5.6                          |
| 3. compaction cycle   | 2.378                  | 99.4                         | 3.6                          |

7.1. Workability and compactability of asphalt mixtures

Correct paving and compaction is crucial for proper function of heavily loaded surface course. During compacting of asphalt layer ACO 11 S PmB 25/55-75, a compaction experiment was performed, in which compaction of layer immediately after laying by paver and then between passes of the rollers was measured by nondestructive nuclear gauge Troxler 4640 B. Individual measurements and reached values of bulk density and degree of compaction are shown in Table 10 [1].
8. Conclusion
The target of above described research task carried out in research project TE01020168 CESTI (Center for Effective and Sustainable Traffic Infrastructure) was practical verification of asphalt mixture with polymer modified asphalt binder which has higher degree of modification than conventional used PmBs in the Czech Republic. At first there were performed laboratory evaluations of highly polymer modified asphalt binder PmB 25/55-75, which were compared with results of laboratory tests carried out on conventional PmB 25/55-65 and paving grade bitumen 50/70. Next step for highly polymer modified asphalt binders possible benefits quantification was comparison of this binder with conventional PmB 25/55-65 and paving grade bitumen 50/70 directly in the asphalt mixture. The final step was realization of experimental road section with usage of highly polymer modified asphalt binder from TOTAL company (Styrelf PmB 25/55-75) into the heavy traffic load friction course.

With respect to results of performed asphalt binder laboratory tests there is possible to expect better functional properties and better durability for asphalt mixtures with highly polymer modified asphalt binder. Highly polymer modified asphalt binder PmB 25/55-75 shows much higher resistance of the binder against the thermo-oxidative aging, better elasticity and cohesion, compare with conventional PmB 25/55-65 and paving grade bitumen 50/70. On the bases of carried out tests there can be expected higher resistance against the fatigue and low temperature cracking, stripping and revealing and better resistance against the rutting in case of highly polymer modified asphalt binder usage in to the asphalt mixture.

By the experimental road section realization there was demonstrated that asphalt mixtures with highly polymer modified asphalt binder PmB 25/55-75 are possible to produce in standard way without any adjustment of asphalt mixing plant. The workability of the mixture on the construction site was good during the machinery paving, but little bit worse during the hand paving in conventional temperature. The compactability was very similar like in case of conventional asphalt mixtures with PmB, which was demonstrated by nondestructive density test by nuclear surface gauge TROXLER. The experimental road section will be observed in the future to evaluate field performance of the asphalt layer with highly polymer modified asphalt binder in longer time period.

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