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Asphalt mixtures with a high amount of RAP – case study

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Abstract. A case study of one trial section in the Pilsen region is presented. The pavement in the section was newly constructed in 2015 using one type of an asphalt concrete mixtures with varying RAP content. The constructed surface course comprises of 0% to 50% RAP. In order to restore the aged binder properties and to avoid the embrittlement of the produced mixtures, a rubber-based modifier/rejuvenator was employed. For technological reasons during manufacturing processes, which engage a parallel drying drum, a crude oil-based rejuvenator was also added. This article contains the preliminary data from an on-going project focused on monitoring the properties of bituminous binders contained in asphalt mixtures. The actual bituminous binders were extracted straight after production, after 6 months and after 12 months. The binder characteristics are evaluated using empirical testing as well as functional tests. Low temperature properties are measured by a Bending Beam Rheometer (BBR). The preliminary results show, that the bituminous binders properties change significantly in a relatively short period of time. The progress in binder' characteristics is contradictory to up-to date knowledge. The probability that the phenomenon of diffusion between aged binder and rejuvenator agents occurs exists. Moreover, the data might indicate that the process of rejuvenator evaporation takes place.

1. Introduction

The technology for recycling of asphalt mixtures has been known for several decades [1], but only the development of mixing technologies, production processes and, ultimately, environmental awareness, has led to its massive expansion [2].

In 2015 the Czech Republic produced about 8 million tonnes of virgin asphalt mixtures, whilst 2 million tonnes of asphalt mixtures were available for recycling purposes. It should be added that despite greater awareness of recycling technology in the Czech Republic, only 16% of the amount of available material is recycled in the production of hot asphalt mixtures. When compared with other EU member states, the Czech Republic lags behind in this respect, even when compared with countries that have a similar or even lower amounts of reclaimed asphalt pavement (RAP) material available: Austria 45%, Denmark 52%, Belgium 64%, and for example Finland 100% [3].

If milled material or reprocessed asphalt mixtures from flexible pavements meet the classification criteria according to Czech technical condition regarding recycling material classification (TP 210) and European standards (EN 13108-8), it may be classified as RAP that can be reused in the production of hot asphalt mixtures in the asphalt plant. At present in the Czech Republic, the addition of RAP material is only allowed in mixtures of type asphalt concrete, and the maximum allowance is determined in the National Annex to EN 13108-1 Table NA-E-4.5 Asphalt concrete wearing courses can contain up to 25% RAP material. For the production of hot asphalt mixtures with a higher content



of RAP (more than 25%), the asphalt plant should be equipped with appropriate technologies that preheat RAP material or at least allow its gradual dosing into the pugmill [4].

One of the main parameters for testing the durability of asphalt mixtures is the use of fatigue tests. Furthermore, individual functional parameters are tested, such as stiffness, or low temperature properties. When adding a higher amount of RAP material, there is often concern that the durability and functional parameters of such mixtures are worse than in case of conventional mixtures. Asphalt mixture after the addition of RAP material becomes more rigid due to the aged binder which it contains [5]; the higher level of rigidity then causes greater resistance to permanent deformation [6]. On the other hand, such mixtures may encounter the previously mentioned disorders associated with temperature and fatigue failures [7, 8].

To prevent the above mentioned problems in mixtures with high levels of RAP material, it is important to use one of the methods of "rejuvenating" the aged binder. The normal method of rejuvenation of aged binder is to use softer-grade binder, or to use special additives. Rejuvenation of aged binder is the key process during production, affecting both functional parameters of asphalt mixtures and binders as well as mixture's lifespan [9, 10].

Aside from the effects of rejuvenating agents on the rheological properties of bituminous binder, it is also necessary to examine the durability of such "rejuvenation" in respect to the volatility of some of the added agents as well as the thermo-oxidative instability. Laboratory conditions, in which these tests are usually carried out, don't always accurately simulate the real situation in road construction. In 2015, for the reasons mentioned above, under the new technologies of the State Transport Infrastructure Fund, the construction of a test area was begun, with the application of higher levels of RAP material, which goes beyond the permissible limits stipulated in EN 13108-1 Asphalt concrete. This step will not only test the effects of higher dosing of RAP material, but will also explore the possibility of monitoring the long-term development and verify the influence of rejuvenation agents on the rheological properties of the bituminous binder.

2. Interaction between rejuvenating agents and aged asphalt binder

A crucial step during asphalt recycling is the process of mixing [11]. After manufacture, the consistency of the rejuvenated binder should be uniform and equal to virgin binder which would be chosen for the new construction without the use of RAP. However, blending aged binder and other constituents (virgin binder + rejuvenator) is a complex process which does not have to occur necessarily already in the course of the mixing period but continues until the equilibrium in consistency is reached over the majority of the asphalt film thickness [12]. During manufacture, the constituents are being continuously mixed; the rejuvenator is simultaneously attracted to virgin and aged binder. Both materials start to soften albeit in different rates. Also the procedure used to determine the optimal amount of rejuvenator and the way of dosing during recycling operation are focal points in mixture design [13]. Figure 1 illustrates possible options acquired after mixture manufacture which might be acquired through mixture manufacture which were proposed by Kriz [14].

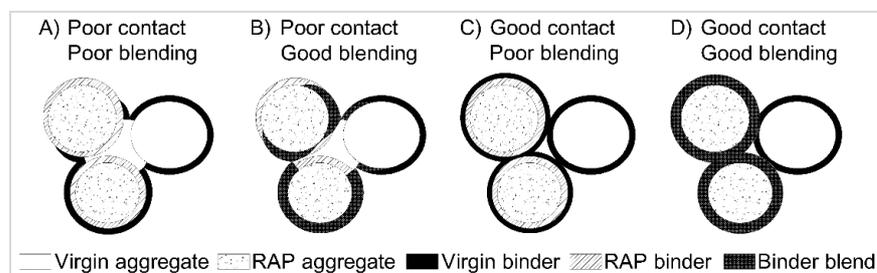


Figure 1. RAP-virgin binder contact and blending due to diffusion. Schematic representation of possible options after manufacture [14].

When it comes to a poor blending occurs (A), binder properties vary within the mixture. Although a rejuvenator might diffuse into the aged binder in the subsequent period following mixing process, binder homogeneity remains low leaving the mixture prone to failures (B). Rejuvenator added into the new fresh bitumen can also form a thin uniform layer that surrounds aged binder. Nevertheless, the blending process might not accomplish during manufacture period because the diffusion process is too slow which in turn causes the mixture being too stiff after production (C). Only when a sufficient degree of blending is reached, the functional properties are predictable (D) [14]. Furthermore, Kriz concluded that the rate of diffusion is greatly influenced by the binder film thickness and temperature.

From the above it is seen that the diffusion and subsequent material (rejuvenator) transport procedure are important processes in obtaining long-term performance of recycled asphalt pavements.

The process of diffusion might be in lab conditions simulated by the method of step extraction. Multi-stage extraction method was utilized in the work of Nourdelin and Wood in 1987 [15], lately supported by the work of Huang [16]. Both studies agreed that in most cases a multilayered system occurs after manufacture period instead of having well blended material with uniform properties. Comprehensive study conducted by Navaro [17] concluded that the degree of interaction between constituents is a function of both parameters, i.e. temperature (aggregate and RAP) and mixing time. It is therefore a major issue, yet not fully solved, to predict a degree of blending and particularly interaction between individual constituents within rejuvenated binder after mixture manufacture at a plant.

The reason for the actual situation is that there is an overabundance of products with different origin (petroleum, bio-based, artificial) and characteristics (viscosity, chemical composition, flash point, etc.) available on the market and no one really knows how they in fact affect individual performance characteristics and how they impact aged binder especially from a long-term perspective. In spite of this, all producers claim that the products significantly improve binder performance [18, 19 and 20].

It is reasonable to assume that the compatibility among binder constituents is the key parameter which governs rejuvenated binder's long term performance. Incompatible oils or rejuvenator overdose can result in a migration of light oils which results in bleeding or flushing and also getting the base binder harder [21]. The migration of light substances of which are some rejuvenators unquestionable composed off is promoted by heat [22].

3. Objectives

The main objective of this paper is to present and compare test results of bituminous binders which have been obtained through extraction and subsequent distillation of asphalt mixtures with different amounts of RAP.

Part of the aim is then the description of the effect of rejuvenation / modification additives on the properties of the bituminous binder over time.

4. Trial section description

The test section is located in a rural area between the villages of Mrtník and Kaznějov in the Plzeň region, on road number II / 204.

The total length of the test section is 2.765 km, which is divided into four subsections. The average daily traffic volume on this stretch of road is 1306 vehicles in 24 hours (RMD traffic census 2010) and the traffic load on the road is as follows: 466 heavy vehicles, 823 cars and 17 motorcycles. There is a kaolin quarry nearby and it can therefore be assumed that the road will be greatly burdened by heavy freight transportation.

5. Materials

5.1. Road construction

During reconstruction an experimental type of asphalt concrete mixture was used, designed as asphalt concrete for surface courses (ACO 11+), with a graduated dosing of RAP material. Optimum amounts of bituminous binder and grading curve for the individual mixtures were chosen to meet the requirements stated in EN 13108-1. The composition of each mixture is described in Table 1. These in a plant produced mixtures were designed and manufactured so as to hold all possible variables during the production process constant (binder content, discharge mixture temperature, virgin bitumen type) except for the amount of RAP.

Table 1 Individual wearing course mixture designs

Section	Designation	Bitumen binder	Modifier/rejuvenator (A)	Rejuvenator (B)	RAP content	Binder content
1	1.1	50/70	YES	NO ¹	0%	5,5%
2	2.1	50/70	YES	YES	30%	5,4%
3	3.1	50/70	YES	YES	50%	5,5%
4	4.1	PMB 45/80-65	NO	YES	30%	5,4%

Table 1 also indicates the content of the bituminous binder, which is closely related to the thickness of the asphalt film.

5.2. Rejuvenating agents

Rejuvenation / modification agent (A) is composed primarily of rubber granules with a maximum size of <1 mm, whose properties are modified by the addition of Fischer Tropsch wax and oil, which is obtained during the distillation process of petroleum products (additive B). Additive A was dosed in the amount of 13% of the weight of bituminous binder (virgin + aged) in the resulting mixture according to the manufacturer's recommendations. Since this additive contains mainly rubber granules, the manufacturer states that the addition of this agent during the manufacturing process will result in modification of the bituminous binder and the resulting mixture should thus behave the same way as after the use of modified binder. Characteristics of this modifier were the ground for also choosing the polymer modified binder (PMB) in the project with the aim to compare these two.

Due to technological reasons during the manufacturing process of a mixture in the mixing plant using a parallel drum, petroleum based oil (ingredient B) was also added to the mixtures containing RAP material, in the amount of 0.2% of the weight of RAP material.

5.3. Reclaimed asphalt pavement material

During production process each mixture containing RAP material was made using mixed RAP categorized as RA 0/11. Before manufacturing the material was rescreened and homogenized using a granulator, which is specially designed to avoid excessive formation of fine particles which would preclude adding larger amounts of RAP without further screening process. The proper screening process ensures the RAP is of excellent homogeneity. Figure 2 shows the granulator along with a detail of the shaft in the milling chamber. In the background of the figure 2 is an asphalt plant equipped with a parallel drying drum, which was used during the production of the mixtures.

¹ Rejuvenator B was not purposely dosed because the mixture contains no RAP material. However, rejuvenator B is a compositional part of modifier/rejuvenator A



Figure 2. Reclaimed Asphalt Pavement granulator (left), a detail of the crushing chamber with the milling shaft (right), an asphalt plant with the fitted parallel drying drum in the background.

5.4. Mixture production

Reclaimed asphalt pavement material was heated prior to mixing to 130°C. The temperature of mixture discharged from the pugmill was set to 170°C for mixtures with paving bitumen and 180°C for polymer modified bitumen.

5.5. Material collection

All asphalt mixtures were collected at the plant straight after production. Subsequently, the cores were sampled at the construction site after 6 and 12 months. The cores after 12 months were drilled right next to the cores which were taken after 6 months in order to have comparable materials.

6. Methods

The binder was extracted according to EN 12697-1 using a centrifuge and recovered by using a rotary evaporator according to EN 12697-3. Solvent used during distillation was trichloroethylene (TCE). Empirical tests which were carried out were: Penetration test determined according to EN 1426 at 25°C and Softening point test determined according to EN 1427. Low temperature behavior was tested by means of Bending Beam Rheometer according to EN 14771.

7. Results and discussion

7.1. Empirical testing

Bituminous binder at the present trial section was extracted from the mixtures after production and after 6 and 12 months from the date of construction. Figure 3 shows the test results of needle penetration and softening point graphically. Table 1 also indicates the content of the bituminous binder, which is closely related to the thickness of the asphalt film. The thickness of the asphalt film is important to the age-resistance of the bituminous binder. If the binder content in the mixture is lower, the thickness of the bituminous film would be also lower. This would result in a lower resistance of the bituminous binder especially against oxidative aging and individual characteristics would be not comparable.

Penetration values measured on extracted binders from mixtures with paving grade bitumen after manufacture (1.1, 2.1 and 3.1) produced a very small variance, which implies that the penetration is not adversely affected by the presence of RAP material, even in the case when a mixture contains 50% of RAP material. The almost equal penetration values (binder 1.1, 2.1, 3.1) after manufacture mean that aged binder was softened already during manufacture.

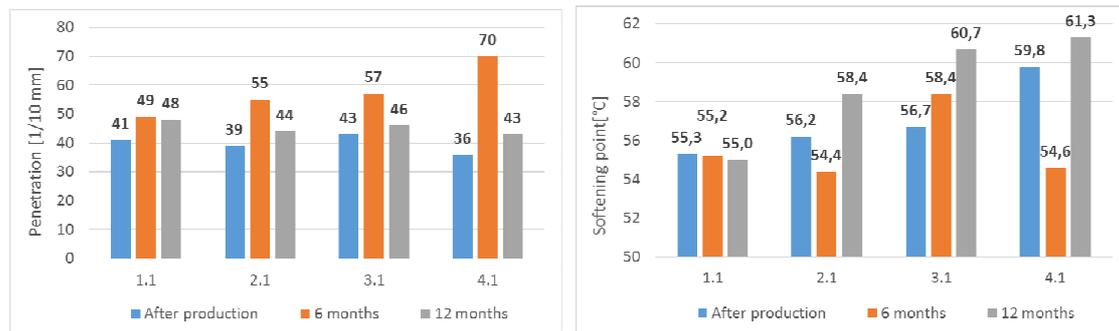


Figure 3. Empirical test results in the given period of time – Penetration (left), Softening point (right).

Likewise, the values of softening points in mixtures with paving bitumen after manufacture fluctuated within a very narrow interval of 56 ± 1 °C. The results of empirical tests also show that after 6 months the penetration of all binders increased, including modified binder. The value of penetration increased by a value of 20% (mixture 1.1) to a value of up to 94% (mixture 4.1). This suggests that during production of asphalt mixtures with RAP at plants there does not have to occur a complete blending process among individual constituents as described in chapter 2. This would mean that even after laydown operations, there is still an interaction between the rejuvenating agent and the aged binder – the rejuvenation agent diffuses further into the aged binder, thus changing its properties and "soften" it. This development in penetration values is contrary to the generally known fact, which says that binder becomes stiffer with age and that over time the penetration value decreases and the softening point increases [23]. Mixtures which contain rejuvenation agents can therefore display completely the opposite behavior.

After 12 months, "softening process" is no longer present, but instead we see a noticeable decline in the values of penetration compared with the values after 6 months. In the case of a mixture free of RAP material (1.1) there is the smallest drop, only about 2%. For other mixtures which contain RAP material, the decrease in penetration value is more pronounced: mixture 2.1 shows a drop of 20%, mixture 3.1 of 19% and mixture 4.1 of 39%. Penetration values after 12 months tend to return to the original values after manufacture.

Looking at Figure 3, it can be seen that mixture 4.1, which contains the modified binder PMB 45/80-65, shows the biggest changes in empirical values. In this case, rejuvenation additive B (oil) was only dosed in a minimal quantity; 0.2% of the weight of the RAP material in the mixture. When comparing mixtures 2.1 and 4.1, which used different binders but the same content of RAP material, it is possible to state that even small amounts of rejuvenation petroleum based oil change the behavior of the modified binder substantially more than in the case of paving bitumen. This behavior may be caused by a reaction between rejuvenation agent and modifiers contained in PMB. The presence of oil might degrade the actual modifier. However, this findings would need to be further proved.

7.2. Functional testing – Bending Beam Rheometer (BBR)

Table 3 compares the various parameters that are measured by BBR. For comparison purposes temperature of -16 °C was employed.

Table 2. Comparison of individual parameters obtained during low temperature measurement by BBR

Designation	Creep Stiffness S_m [-16°C]			m-value [-16°C]		
	After production	6 months	12 months	After production	6 months	12 months
	[MPa]	[MPa]	[MPa]	[-]	[-]	[-]
1.1	119.0	80.5	88.5	0.333	0.333	0.341
2.1	108.3	79.1	105.4	0.326	0.346	0.325
3.1	111.7	78.9	102.8	0.323	0.361	0.35
4.1	136.5	52.8	131.6	0.344	0.429	0.382

The presence of RAP material in mixtures 2.1 (30%) and 3.1 (50%) does not adversely affect the creep stiffness of the bituminous binder compared to the reference binder from mixture 1.1 after production. After 6 months there was a decrease in creep stiffness of 27% in the case of binder 2.1,

30% for binder 3.1 and of 61% in the case of binder 4.1. Even at low temperatures, the properties of modified binders are affected more significantly by rejuvenating agents than in case of paving bitumens. Binders extracted from mixtures with RAP material after 6 months have also improved their ability to relax, which is evidenced by the increase of m-value and the consequent decrease of the critical temperature. On the other hand, it is seen that after 12 months, creep stiffness increases compared to the situation after 6 months, by 10% for mixtures 1.1 and as much as 149% for mixture 4.1.

Figure 4 graphically illustrates the resulting critical temperature, which has been calculated based on measurements at three different temperatures (-16°C , -22°C and -28°C). The critical temperature is always the greater of the two values.

It is clear that rejuvenating agents have a major impact on low temperature properties. The most striking changes can be observed at critical temperatures, calculated on the basis of m-values. In a time period of 6 months there was a change in the temperature of binder mixture 2.1, which at production had a critical temperature of 20.3°C , of about 13.3°C and then 12 months after laying the value is the same as after manufacturing.

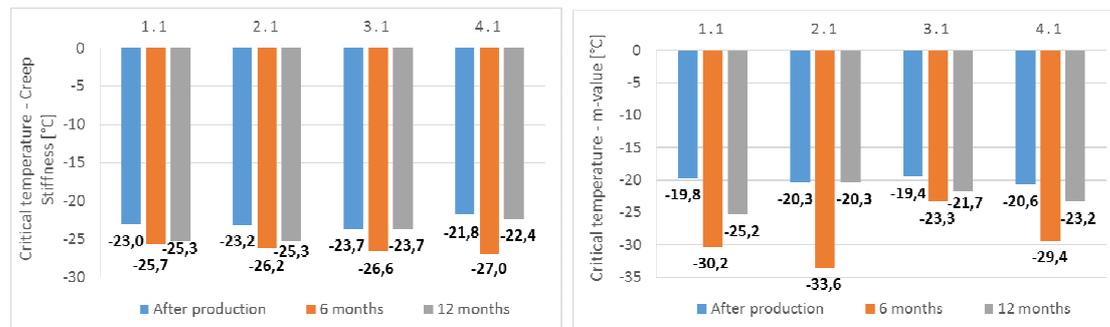


Figure 4. Critical temperatures based on creep stiffness (left) and on m-value (right).

8. Summary of results

The aim of the tests was to compare the rheological behavior of bituminous binders extracted from asphalt mixtures with different amount of RAP material. The properties of individual binders were tested immediately after production and then after 6 and 12 months from the date of laydown operations. Partial task was to determine the effect of RAP material on properties of the bituminous binder and to what extent these properties are affected by the presence of rejuvenating agents.

The following observation were made during the first 12 months of testing :

- The needle penetration test found that all the binders displayed increased penetration 6 months after laying by 20% to 41% for mixtures with paving bitumen. The most striking changes were observed for the mixture with the modified binder which showed an increase of 94%. At the same time, after 6 months a decrease in softening point occurred. After 12 months the "softening" process ceased, a characteristic which was observed in all mixtures regardless of RAP material presence. Penetration decreased after 12 months in comparison to the situation after 6 months whereas the softening point increased.
- With regards to low temperature properties creep stiffness decreased in all bituminous binders after 6 months as well as the critical temperature, T_c . Reduction of creep stiffness at low temperatures corresponds with the results of empirical tests and tests on DSR - the 6-month-old binder is "softer". When comparing individual binders, mixture 4.1, which contained the modified binder, reached the lowest critical temperature both after production and after 6 months. After 12 months, it can be seen that it loses its original effect of "rejuvenation"

(softening) of the binder. The resulting critical temperature values were closer to their initial state after manufacture.

9. Comments and discussion

The first round of extraction (results after manufacture) was performed on mixtures taken at the plant, whereas the extraction after 6 and 12 months was conducted on cores drilled at the site. This means that the first extraction could have been theoretically conducted on a material which lies in the same section where the cores were taken but on a different spot, i.e. the mixture is of the same designation but from a different manufacturing batch. Therefore, the dosing of the rejuvenators could vary slightly because of the dosing device deviation as well as of the properties of RAP binder due to possible inhomogeneity. Nevertheless, it is seen that the softening effect after 6 months occurred for all mixtures (even in the case of mixtures from binder courses – not mentioned in the article) and therefore the results are assumed to be correct. Thus the authors anticipate that the process of rejuvenator diffusion took place after laydown operation.

The weak point of the study is the process of distillation carried out according to EN 12697-3. During the extraction process all binder constituents are mixed together and homogenized. Supposing that the same amount of rejuvenator is present after manufacture as well as after 6 months, the binder characteristics should be equal, provided the homogenization occurs during distillation. The authors are not familiar with any study which would be focused on these points at issues (rejuvenated binder distillation) and thus cannot confirm or deny the above mentioned statement. However, the authors admit that the acknowledgement of the presence of the diffusion processes should not be based solely on the data provided in the article. Diffusion process might have been detected and confirmed by multi-stage extraction which was not carried out.

Another ground for binder softening after 6 months might be an incomplete washing process during extraction. Such error would leave harder binder stuck to aggregate. The authors find this option as highly improbable as this would have to be case for all mixtures. Moreover, aggregate was checked upon washing stage for traces of binder.

The cores studied after 6 and 12 months were drilled exactly at the same spot which in any case means that the tested materials are from the same batch, with the same amount of rejuvenator, rejuvenator distribution and with the same RAP material. Here is therefore no space for any misconduct in terms of material substitution. In this case, the authors suppose that the decrease in penetration after 12 months compared to 6 months might be explained by the phenomena of rejuvenators' migration. Higher ambient temperatures during summer season promoted oily substances to migrate. The trend of penetration decrease manifested itself in all mixtures.

The obtained data provide new insights into the behavior and development of the properties of the bituminous binder contained in mixtures with the addition of a higher amount of RAP material. The results are particularly unique, because they confirm that there is an interaction between the rejuvenating agent and aged bituminous binder contained in RAP material after manufacturing and laying period.

10. Perspective

Further research should be undertaken to confirm, whether the process of diffusion occurs and what rate of rejuvenator transport might be expected. The study focuses on interaction between rejuvenator and asphalt binder during the process of extraction and especially distillation according to EN 12697-3 is a must. As a further step, another trial section is planned in the Czech Republic using various kinds of rejuvenators. Validation of the diffusion process by multi-staged extraction should take place.

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