Recycling of asphalt at the mixing plants in the Czech Republic

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ABSTRACT

The article deals with the recycling technology of asphalt done at the mixing plants in the Czech Republic. The nowadays used methods are described. A greater attention is paid to the technology with the use of pararell drying drum. This additional equipment, which can be found only on 4 mixing plants in the Czech Republic, is able to preheat and add RAP in the amount of up to 80 %. The research, which has been done with asphalt mixtures with various amount of added RAP with the use of rejuvenators is described. The comparative measurements, carried out with the use of functional tests as wheel tracking test, measurement of stiffness modulus, fatigue and water sensitivity test are published.

Keywords: Asphalt, Mixing plant, Reclaimed asphalt pavement (RAP) Recycling, Rejuvenators

1. INTRODUCTION

Recycling of building materials is an essential prerequisite in sustainable development and in overcoming the conflict between economic growth and environment protection. Flexible road constructions are an important material resource, from which milled asphalt mixtures can be used during repairs and reconstructions for manufacturing new mixtures processed at high temperatures. The main reasons for recycling asphalt layers are given below:

Conservation of material and energy sources

- Material sources (aggregate, bituminous binder)
- Energy sources (fuels, heating media etc.)

Environment protection

- Reduction of greenhouse gas emissions, especially CO_2
- Reduced air pollution (exhaust gases, noise)
- Less landfills

Economic benefits

- Cost reduction
- Decreased loading of the roads

2. CURRENT STATE ANALYSIS AND PLAN FOR IMPROVEMENT

In long term it is now possible to see a continual increase in the prices of oil and its derivatives. Recycling of milled material from compacted asphalt layers is therefore an essential perquisite of responsible management of natural resources such as aggregates and bituminous binders. Incorporating RAP into asphalt mixtures processed at high temperatures is its most effective use. In this perspective, the Czech Republic is not at the same level as other Western European countries, because first of all there are no effective incentive mechanisms for effective use of RAP, there are unjustified concerns about the quality of asphalt materials with higher RAP content among the investors and in addition there are often excessive concerns about the impact on the environment as well. Also with regards to the effective national annexes of the European standards for asphalt mixtures processed at high temperatures, there is indeed a potential for higher RAP dosing.

2.1 Analysis of the current state in the Czech Republic

In the Czech Republic, there is currently approximately 30 % of batch asphalt mixing plants equipped with facilities for incorporating cold RAP into hot asphalt mixtures manufactured. The RAP dosing is performed in the cold way either directly into the mixing device or the RAP is stored in a container just like the other aggregate fractions and is then dosed using a weight just like the aggregate. This type of processing, however, only allows addition of a maximum of 20 % of RAP from the overall weight of the asphalt mixture. This limitation is due to the requirement of pre-heating the aggregate to a higher temperature with respect to the resulting temperature of the mixture and also due to the moisture in RAP.

Apart from the above mentioned asphalt mixing plants, which are equipped with an additional facility to dose RAP, there are only 4 batch asphalt mixing plants in the Czech Republic equipped with parallel drying drum for pre-heating of RAP, and one continuous asphalt mixing plant of the drum-mix type. In the parallel drum batch asphalt mixing plants, the RAP is heated to a temperature of approximately 120 to 130 °C, which enables substantially higher percentage of dosing. In a continuous asphalt mixing plant, the RAP is dosed in the middle section of the drying and heating drum continuously, and subsequently it is mixed with the aggregate and asphalt mixture, or alternatively the mixing is performed in a separate mixing unit. These two processing types enable adding a higher proportion of RAP, in case of the parallel drying drum it is up to 80 %, in case of the drum-mix technology, the maximum is approximately 50 %.

Figure 1: Batch mixing plant with parallel drum

2.2 Possible improvements of the current state

In other countries, much more attention is given to the preprocessing of RAP before it is processed, in comparison with the Czech Republic. Important aspects, which would allow substantially higher quality of manufactured mixtures with RAP, its higher dosing and thus also cost reductions, are outlined below.

Milling in layers and storing RAP separately

When storing the RAP separately based on the individual construction layers (wearing course, binder course, base course) and using it again in the same layer, a material with approximately the same granularity is used and it is not necessary to analyze the quality of the aggregate too much, because it can be assumed that it has already been previously verified. From this perspective, processing RAP is then easier and it is possible to use higher doses. Storing unsorted RAP from all construction layers together on the other hand, leads to its degradation.

RAP homogenization before subsequent processing

Homogenization of RAP is essential for maintaining its quality, especially in cases where RAPs of various origins are stored together. Homogenization also leads to even distribution of granularity even in different binder materials. Material homogenization can be considered as one of the key factors, which subsequently determine maintenance of continuous quality of the asphalt mixture.

RAP crushing

Both milled RAP and RAP in blocks should pass through a crusher and sieves, where foreign materials (e.g. metals, wood and plastics) are removed and RAP conglomerates are reduced to the desired size. In common practice, the material is crushed into two basic fractions 0/11 and 0/22, which are added to the individual mixtures based on the maximum grain size. A crusher from the Bennighoven manufacturer proved to give very high-quality results. When using this crusher, the milled RAP and RAP in blocks are placed into a funnel and by gentle rotation of the rotor with teeth, the conglomerates are gradually getting smaller (see Figure 2). In case of this crusher, there is almost no crushing of the aggregate grains, which has been proven by sieve analyses before and after crushing, performed after binder extraction.

Figure 2: Special crusher for RAP

Roofing aggregate and RAP storage → moisture reduction

Roofing the storage facilities prevents rain water to penetrate into aggregate fractions and the actual RAP and this subsequently also leads to reduced fuel consumption (gas, fuel oil etc.) during aggregate preheating in a drying drum or RAP pre-heating in parallel drying drum.

Continuous monitoring of binder parameter quality and granularity in the RAP storage facility (softening point, penetration, binder content and granularity after extraction)

To ensure high-quality of the resulting asphalt mixture it is necessary to continuously monitor its parameters. The European standard EN 13108-8 [2] requires stating its parameters either based on softening point, or its penetration. RAP where the extracted binder does not reach an average softening point value of 70 °C (individual values max. 77 °C), is suitable for being used for a new asphalt mixture manufacture. Similarly, binder with an average value not lower than 15 pen. can be processed. Determination of both parameters must be performed using homogenized RAP.

In case of exceeding the above stated values (Ø R&B >70°C or Ø penetration < 15 pen.) it is necessary to verify the suitability of the RAP for the resulting mixtures using functional tests – for example a test for resistance against frost crack formation with respect to increased binder stiffness and thus also the stiffness of the overall asphalt mixtures. In this case it is convenient to compare properties of this mixture with properties of a mixture, where only new materials were used (both bitumen and aggregate).

In addition, it is necessary to monitor also binder content and particle size distribution of the RAP after binder extraction. It is sufficient to monitor particle passing a 0,063 mm sieve, 2 mm sieve and nominal sieve.

Aggregate in RAP must confirm to the particular requirements of the standards
In order to use RAP as a substitute for larger proportion of the aggregate in an asphalt mixture, it is necessary to gather the necessary information regarding quality of the initial aggregate from available sources, for example based on the available results from the initial type testing ITT. RAP samples are always tested to determine sample granularity and granularity after extraction. If other parameters are not available, the following parameters of the RAP are determined:
- Aggregate type,
- Shape index,
- Ratio of fraction surface on the grains (crushed/rounded grains),
- Mechanical resistance in LA test,
- Polished stone value,
- Water absorption of aggregates,
- Frost resistance

Monitoring the presence of tar in RAP
Tar presence also means the presence of health threatening PAH (Polycyclic Aromatic Hydrocarbons) and it is necessary to be able to assess this using a quick and simple method. One of such methods is for example a method that uses white color, where lower or higher amount of tar can be deduced from brown coloring.

3. RESEARCH PROJECTS OF TECHNOLOGY AGENCY

The aim of the Technology Agency of Czech Republic research project TA02030549 called "Maximal effective use of recycled road asphalt layers for the production of new asphalt mixtures" was to analyse the innovative technology of recycling various types of asphalt mixtures of flexible road constructions and using them in newly manufactured mixtures thanks to the addition of special types of chemical additives designed to enable dosing of high RAP content. After the end of work within this project, further experiments are continuing in the frame of the Competence Centre TE01010168 "Centre for Effective and Sustainable Transport Infrastructure (CESTI)" also co-financed by the Technology Agency of the Czech Republic.
The recycled material was supposed to be used in the maximum possible extent in asphalt mixtures, which in terms of their quality and usability matched standard mixtures with no RAP. The technology developed in these projects is supposed to be in terms of technical design and manufacture possible to perform in the same way as standard asphalt mixture. Also environmental factors were monitored, in particular recyclability, reduction in energy consumption and extension of road construction lifetime.

3.1 Mixture design

Working on the project began by a literary review and experimental design of asphalt mixtures with verification of their functional properties. The particular asphalt mixtures used were mixtures of asphalt concrete type for binder courses (AC 22 bin) and asphalt concrete for base courses (AC 22 base). All the mixtures were designed in a laboratory with various RAP content (AC 22 bin and AC 22 base with 0 %, 30 %, 50 % and 70 % RAP content) and optimized for binder content of 50/70 during initial type testing ITT. Fluxoils Storflux and Storbit were used to soften the asphalt binder in RAP. The aim during the design process was to achieve ideally the same particle size distribution in all mixtures and overall asphalt content ratio of the individual mixtures, so that the designed mixtures could be compared in subsequent laboratory tests of functional properties. The particular tests chosen for this purpose are listed below.

Table 1: Basic bitumen tests for the added bitumen 50/70

	Measured values	EN
Penetration [pen]	59	50 -70
Softening point [°C]	48,1	46 – 54

Table 2: Basic bitumen tests for the bitumen extracted from RAP 0/22

	Measured values	Bitumen content in RAP
Penetration [pen]	25	4,7 %, 4,5 % Ø 4,6 %
Softening point [°C]	59,2	

Table 3: Sieve curve of RAP 0/22 and resulting sieve curves for AC 22 bin and AC 22 base

	Bitum. content %	22 mm	16 mm	11 mm	8 mm	4 mm	2 mm	1 mm	0,5 mm	0,25 mm	0,125 mm	0,063 mm
RAP 0/22	4,6	98	93	83	69	47	34	25	19	14	10	8
AC 22 bin 0 % RAP	4,4	99	92	76	62	42	31	23	18	14	11	8,8
AC 22 bin 30 % RAP	4,4	99	90	73	60	41	30	22	17	12	10	7,7
AC 22 bin 50 % RAP	4,4	99	91	74	60	42	30	22	17	12	9	7,5
AC 22 bin 70 % RAP	4,4	99	92	75	60	40	30	22	17	12	10	7,8
AC 22 base 0 % RAP	4,3	98	79	61	50	33	25	20	16	14	11	9,1
AC 22 base 30 % RAP	4,3	97	77	63	53	34	25	20	17	14	12	9,2
AC 22 base 50 % RAP	4,3	97	75	63	53	35	26	21	17	14	11	9,1
AC 22 base 70 % RAP	4,3	97	77	63	52	36	28	22	18	14	11	8,9

Tests on asphalt mixtures:

AC 22 bin
1. Resistance against permanent deformations
2. Water sensitivity
3. Determination of stiffness modulus

AC 22 base
1. Determination of stiffness modulus
2. Determination of fatigue characteristics

3.2 Results of functional tests
In order to prove the effectiveness of the Storflux as a softener of the aged binder in RAP, functional tests of the asphalt mixtures were performed with variable Storflux amounts. Below are the results of selected functional parameters for the individual mixtures with regards to the amount of RAP used.

AC 22 bin – resistance against permanent deformations
Resistance against the formation of permanent deformations determined according to the EN 12697-22 [4] standard was monitored using two parameters: WTS_{AIR} average increase in wheel tracking slope in mm/1000 cycles (from wheel tracking slope measured after 5000 and 10000 cycles) and PRD_{AIR} – proportional rut depth after 5000 cycles. Table 4 shows that resistance against permanent deformations increases with increasing the ratio of RAP.

Table 4: Overview of test results for resistance against permanent deformations (AC 22 bin)

RAP content	Average rut depth after 5 000 cycles	Average rut depth after 10 000 cycles	$d_{10\,000}$-$d_{5\,000}$	WTS_{AIR}	PRD_{AIR}
	[mm]	[mm]	[mm]	[mm/1000 cycles]	[%]
0%	0,93	1,10	0,17	**0,034**	**1,6**
30%	0,66	0,76	0,10	**0,019**	**1,1**
50%	0,59	0,67	0,08	**0,016**	**1,0**
70%	0,78	0,86	0,08	**0,016**	**1,3**

AC 22 bin – water sensitivity

Water sensitivity was tested according to the EN 12697-12 [3] standard on specimens compacted with 2x25 impacts. Half of the specimens were left in dry conditions, while the other half were vacuumed in a vacuum pump and left in a water bath at 40°C for 72 h. The ITSR ratio shows the ratio between the indirect tensile strength of wet and dry specimens. As can be seen in Table 5, higher RAP content does not have any negative effects on water sensitivity.

Table 5: Overview of the results from water sensitivity tests (AC 22 bin)

RAP content	Conditions	Ø ITS	ITSR ratio
		[kPa]	-
0 %	Dry	1347	0,81
	Wet	1659	
30 %	Dry	1244	0,94
	Wet	1330	
50 %	Dry	1250	0,87
	Wet	1441	
70 %	Dry	1355	0,93
	Wet	1452	

AC 22 base – stiffness moduli

Stiffness moduli were determined using trapezoidal shaped specimens and two-point bending test (2-PB) according to the EN 12697-26 [6] standard. Trapezoidal shaped specimens were cut out from slabs compacted with a compactor with roller running on vertical sliding steel plates. The slabs were compacted so that the compaction ratio ranged between 99 % and 101 % with respect to the specific gravity from the type test determined at optimum binder content. Stiffness moduli were determined at a temperature of 15°C and frequency 10 Hz. As can be seen in Table 6, thanks to the Storflux rejuvenator, the stiffness moduli for various RAP content are comparable. Similar values of dispersion were also observed in case of specimens cut out from slabs for binder courses.

Table 6: Stiffness moduli (AC 22 base)

RAP content	Specimen Ø 1-5	Specimen Ø 6-10	Specimen Ø 11-15	Ø
	[MPa]	[MPa]	[MPa]	[MPa]
0 %	9723	9752	9377	9617
30 %	9711	9844	10232	9929
50 %	10173	9375	9619	9722
70 %	9412	9089	9720	9407

AC 22 base – fatigue characteristics

For base courses, also the fatigue characteristics were determined, in accordance with the EN 12697-24 [5] standard. The fatigue test was performed at 18 trapezoidal shaped specimens at a temperature of 10°C and frequency 25 Hz. The results from this test are given in Table 7 below. The results show that the major parameter in the evaluation of fatigue "ε_6" increases as the RAP content increases, so best result for fatigue characteristics was obtained for the 70 % RAP content. A possible explanation for this could be the high content of the Storflux additive in the designed mixture, which however is proportional to the amount of bitumen in RAP.

Table 7: Fatigue characteristics (ACP 22 base)

RAP content	ε_6	B
0 %	107,4	4,8
30 %	121,2	4,3
50 %	130,6	4,9
70 %	138,2	5,2

4. CONCLUSION

Based on the results of the AC 22 bin and AC 22 base mixture designs it was proven that adding softeners based on fluxoils to mixtures with RAP can achieve water sensitivity, stiffness moduli, fatigue characteristics and resistance to permanent deformations at least equal to mixtures without RAP. The amount of Storflux and Storbit used was based on manufacturer´s recommended value of 1 % of the bitumen amount in the RAP for lowering softening point by 1 °C. In this way, it was also proven by long-term tests that using up to 70 % of RAP does not have any negative effects on the quality of the final mixture.

A question which was not dealt with in this paper is to what extent the rejuvenator softens evenly the aged binder and how well the aged binder of RAP and newly added binder mix together.

Despite the fact that the project successfully ended, work continues in the Competence Centre in order to combine the findings from laboratory conditions during mixing with mixing conditions in asphalt mixing plants. Laboratory mixing is performed using substantially different mixing devices and different mixing times, much longer than in the asphalt mixing plant. This leads to different mixing of the binder with RAP and the new binder because mixing times in the asphalt mixing plant are much shorter than in the laboratory. The effect of other possible additives is now being investigated, such as the additive Storelastic, which modifies the binder with crumb rubber, contains fluxed oil for softening the binder in RAP and also contains waxes, which enable lowering the temperature during processing of the whole mixture.

Recently a research has been published which summarizes the latest findings and experiences with using RAP in asphalt layers. New methods were identified, which can be used in order to determine the extent of remobilization of the old binder and thus estimate the properties of the newly manufactured asphalt mixture. Extent of remobilization of a binder has a fundamental effect on the functional parameters of the mixture. Some experimental methods intended to determine the remobilization extent of old binder proved they are highly reliable and proved the possibility to determine homogeneity/heterogeneity of the mixture based on the results of these tests. However, it must be noted that these methods are relatively complex and difficult to perform in standard road laboratories; therefore research is currently geared towards determining mixture parameters using “standard” laboratory techniques.

It can therefore be concluded that using high ratios of RAP in asphalt mixtures is technically possible, but lot of questions still remain to be solved in order for the whole recycling technology to be technically at a high level.

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