THE EFFECT OF ADDING RECLAIMED ASPHALT IN DIFFERENT TYPES OF ASPHALT IN DIFFERENT AMOUNT

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ABSTRACT

Denmark has for many years a system for collecting all types of asphalt for recycling. Milled and broken asphalt of all types is collected at all asphalt plants and when 10.000 - 20.000 tons has been collected it is crushed and eventually sorted in different fractions. This crushed RAP is normally used in new base course asphalt or binder course asphalt in amounts of 15 - 40 % depending on the type of asphalt plant and the type of new asphalt.
Because the collected RAP contains aggregates from base course materials with natural sand and materials from gravel, the RAP can only be used in very small amounts in new wearing courses, normally 0 - 5 % depending on the type of new wearing course.
The amount of asphalt for recycling is growing dramatically and therefore NCC has started to sort the incoming asphalt for recycling. Milled wearing course material is stockpiled separately from milled base- and binder course material and broken asphalt. The milled wearing course RAP is used in new wearing courses. Different types of wearing courses have been produced with different amounts of RAP. The influence of the RAP on the bitumen quality and the asphalt properties has been tested and the results will be presented.

Keywords: recyling, RAP, asphalt, wearing course, base course

1. INTRODUCTION

Until a few years ago Denmark had balance between the amount of collected RAP and the amount RAP used in new asphalt materials. Milled and broken asphalt of different types have been stacked up in the same stockpile. The crushed RAP was primary used for new base course materials because it was a mix of many different asphalt types and with impurities of uncrushed gravel from sub bases. Within the last 3 – 4 years a large upgrading program for the motorway pavements has been launched and many thousand tons of milled wearing course are collected. According to the environmental authorities approximately 1 million tons RAP is collected and only one third is reused in new hot mix asphalt [1]. Alternative procedures had to be developed if the RAP should be used in wearing courses. Old milled wearing course should be handled separately and used in new wearing courses.

This paper describes the Danish tradition of using RAP in different types of asphalt and how old milled wearing course has been used in new high quality wearing course material without compromising on quality.

2. REGULATIONS FOR USE OF RAP IN HOT MIX ASPHALT

The use of RAP has been described in a lot of papers, internet pages and conference papers, for example [2] and [3]. In Denmark the use of RAP in hot mix asphalt is regulated in the Danish road specifications [4]:

- RAP is allowed in all base course materials in unlimited amounts
- In wearing course up to 30 % RAP could be used
- In binder course for traffic amounts up to 500 10-ton ESAL 30 % RAP could be used.
- In binder course for traffic amounts above 500 10-ton ESAL RAP is not allowed.

These permitted amounts of RAP are provided that the specifications for bitumen quality, aggregate quality and filler quality in the different asphalt types are fulfilled.

2.1 BITUMEN QUALITY

The bitumen in the new hot mix asphalt with RAP has to meet the specifications in EN 12591. Therefore the bitumen quality in RAP is controlled and the hardness of the virgin bitumen added to the new hot mix is adjusted according to the hardness of the bitumen in the RAP to meet the desired hardness. This is not a problem because all asphalt plants have at least two bitumen tanks, one with hard bitumen (40/60) and one with soft bitumen (250/330 or 330/430).

2.2 AGGREGATE QUALITY

All aggregate material shall meet EN 13043. Denmark only has one quarry on a small island placed in the Baltic Sea. Therefore most of the aggregates for asphalt wearing course production have to be imported from Norway and Sweden. The country has a lot of gravel pits and the materials from these pits are of varying quality but they are allowed in base course and binder course materials under certain limitations (see table 1) [4].

As mentioned in the introduction the stockpile of collected RAP is a mixture of all different asphalt types with both crushed rock and materials from gravel pit (see figure 1). After crushing the RAP could also contain a small amount of uncrushed material, typical below 10 %. Therefore RAP has not been used in high quality wearing courses such as SMA because only totally crushed rock is allowed. Up to 10 % could be used in dense graded asphalt concrete to meet the specification for crushed and unbroken surfaces.

Figure 1: Stockpiles of uncrushed and crushed RAP

Table 1: Danish specifications for aggregate quality in different asphalt types

Asphalt type	Type of aggregate	Content of light components in the aggregate material ≥ 4 mm DS 405.4 *)	Percentage of crushed and unbroken surfaces EN 933-5	Flakiness index EN 933-3	Resistance to fragmentation (Los Angeles) EN 1097-2
Lower base course (GAB II)	No requirements	No requirements	No requirements	No requirements	No requirements
Upper base course (GAB I)	No requirements	No requirements	No requirements	No requirements	No requirements
Binder course for low traffic <200 10-t ESAL (GAB 0)	No requirement	Max. 8 %	$C_{50/30}$ or better	No requirements	No requirements
Binder course for medium traffic 200–500 10-t ESAL (ABB ≤ 500 $Æ_{10}$)	Crushed sand	Max. 8 %	$C_{50/10}$ or better	No requirements	No requirements
Binder course for heavy traffic >500 10-t ESAL (ABB > 500 $Æ_{10}$)	Crushed sand crushed aggregate	Max. 8 %	$C_{100/0}$	No requirements	No requirements
Dense graded asphalt concrete low traffic	Crushed gravel Max. 50 % natural sand in the fines	Max. 6 %	$C_{50/10}$ or better	No requirements	No requirements
Dense graded asphalt concrete medium and heavy traffic	Crushed rock Max. 50 % natural sand in the fines	Max. 6 %	$C_{95/1}$ or better	No requirements	No requirements
Open graded asphalt concrete, SMA, drainage asphalt, ultra thin wearing course	Crushed sand Crushed rock	Max. 6 %	No requirements **)	FI_{20} or better	LA_{30} or better

*) There is no EN standard for this test

**) Because it is specified that crushed rock shall be used no requirements for percentage of crushed and unbroken surfaces is needed.

2.3 FILLER QUALITY

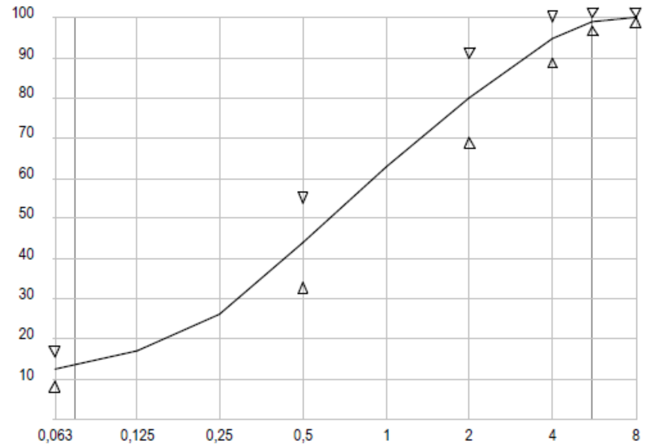
The only requirement is that 1,5 % adhesion improving filler such as cement has to be added to wearing course asphalt.

3 QUALITIES OF BASE COURSE AND BINDER COURSE WITH RAP

When crushing the RAP it often is divided into fractions 0/6 and 0/11. Because of a lot of handling before and after the crushing the final RAP fractions are quite homogeneous and only acceptable variations on bitumen content and gradation curve are observed. Typical specifications for 0/6 and 0/11 are illustrated in figure 2 and 3.

Sieve, mm	Spec.	Min.	Max.
16	100	100	100
11,2	99	98	100
8	95	-	-
5,6	80	70	90
4	70	-	-
2	54	44	64
1	44	-	-
0,5	33	23	43
0,25	20	-	-
0,125	12	-	-
0,063	8,5	5,5	11,5
Bit-%	4,2	3,7	4,7
R&B, °C	57	-	-

Figure 2: Typical specification, 0/11 RAP



Sieve, mm	Spec.	Min.	Max.
8	100	100	100
5,6	99	98	90
4	95	90	99
2	80	70	90
1	63	-	-
0,5	44	34	54
0,25	26	-	-
0,125	17	-	-
0,063	12,5	9,5	15,5
Bit-%	5,0	4,5	5,5
R&B, °C	57	-	-

Figure 3: Typical specification, 0/6 RAP

3.1 LOWER BASE COURSE ASPHALT (GAB II)

As shown in table 1 there are no special aggregate requirements for lower base course asphalt. Therefore natural sand and uncrushed materials from gravel pits are used. In some parts of the country there is a lot of soft limestone aggregates, soft sand stone or flint. The strength of these materials is poor and some of them are water sensitive. Because most of the surfaces are unbroken the stability is relatively low.
When adding RAP to this type of asphalt the quality is improved. A lot of aggregate surfaces in the RAP are broken and the content of crushed rock is high. It is easier to pave and compact without any displacements of the layer and the stability is better. Therefore the companies add as much RAP as the actual asphalt plants can handle.

3.2 UPPER BASE COURSE ASPHALT (GAB I)

There are no special requirements for the aggregates and therefore uncrushed materials from gravel pits are used to a high degree. As for lower base course aggregate quality is improved by adding RAP. As an example data has been collected for a specific GAB I with varying amounts of RAP. The virgin gravel pit aggregates have the same origin. Table 2 shows the data that are mean values of different numbers of samples. All volumetric data and stabilities are similar within the uncertainties showing that RAP does not have any negative effect.

Table 2: **Upper base course asphalt GAB I with varying amounts of RAP.**

Parameter	Unit	RAP content, %			
		0	20	25	30
Bitumen content	%	4,9	4,8	4,5	4,8
Aggregate density	g/cm³	2,678	2,675	2,669	2,677
Asphalt density, Marshall	g/cm³	2,394	2,411	2,376	2,384
Air void, Marshall	Vol-%	3,5	2,8	4,5	4,0
Voids filled with bitumen	Vol-%	77	80	70	74
Marshall stability	N	8950	9150	8300	9000
Deformation	mm	2,7	3,1	2,7	2,7
Material below 2 mm	%	48	49	51	47
Material below 0,063 mm	%	6,7	8,6	7,2	5,7

3.3 BINDER COURSE FOR LOW TRAFFIC (GAB 0)

According to table 1 there are requirements for crushed and unbroken surfaces. Therefore a certain amount of crushed aggregates from gravel pits is added. Adding RAP the quality of the aggregates in the asphalt is improved to a minor degree. Results with different amounts of RAP are shown in table 3. The virgin gravel pit aggregates also have the same origin in this comparison and all data are mean values of different numbers of samples. Also in this comparison all volumetric data and stabilities are similar within the uncertainties showing that RAP does not have any negative effect.

Table 3: **Binder course for low traffic with varying amounts of RAP.**

Parameter	Unit	RAP content, %			
		0	15	20	25
Bitumen content	%	5,1	4,9	4,8	4,8
Aggregate density	g/cm³	2,667	2,663	2,671	2,669
Asphalt density, Marshall	g/cm³	2,397	2,410	2,393	2,405
Air void, Marshall	Vol-%	2,7	2,4	3,0	3,4
Voids filled with bitumen	Vol-%	82	83	79	77
Marshall stability	N	9400	8700	10580	8990
Deformation	mm	3,0	3,3	2,9	3,2
Material below 2 mm	%	43	43	47	47
Material below 0,063 mm	%	5,7	6,4	7,1	7,0

4 QUALITY OF WEARING COURSE WITH RAP

The most used wearing course on motorways is SMA and according to table 1 SMA has to be a combination of crushed rock and crushed sand. 30 % RAP is allowed but then the RAP also has to be a combination of crushed rock and crushed sand. When handling RAP in the normal way it is a combination of a lot of different raw materials. If the specifications shall be fulfilled this material could only be used in new dense graded pavements and this has been done for many years. Up to 10 % RAP is added to dense graded asphalt concrete without any negative influence on the volumetric data (see table 4)

Table 4: **Dense graded asphalt type 8**

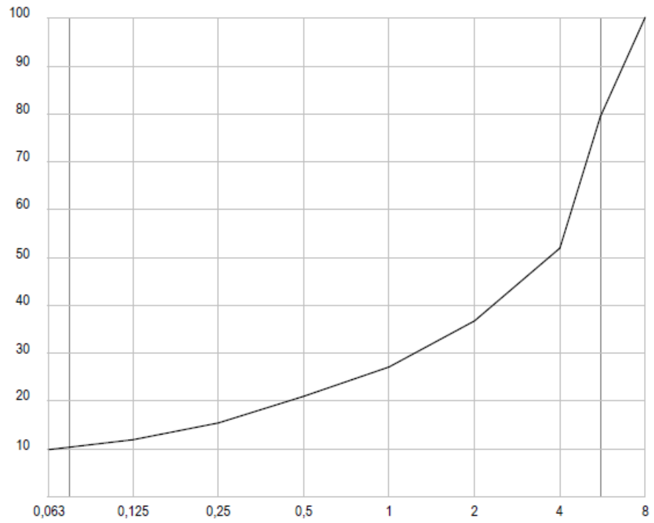
Parameter	Unit	RAP content, %		
		0	5	10
Bitumen content	%	5,5	5,3	5,6
Aggregate density	g/cm³	2,715	2,735	2,728
Asphalt density, Marshall	g/cm³	2,428	2,436	2,432
Air void, Marshall	Vol-%	2,4	3,0	2,5
Voids filled with bitumen	Vol-%	85	81	84
Material below 2 mm	%	50	48	50
Material below 0,063 mm	%	7,8	6,8	7,3

If the RAP has to be used in new SMA pavements the RAP shall, as mentioned before, only contain crushed rock and crushed sand and it is then necessary to sort out RAP from old SMA pavements. This could be done by keeping milled

SMA separated from the normal RAP. This procedure is used in other places with success and very high percentage [3][5], but in Denmark there is no tradition for doing this.
In 2010 and 2011 there have been a lot of milling jobs on motorways and other primary roads where old open graded asphalt concrete, SMA or ultra thin pavements have been milled off. When the milling procedure is made in a very controlled manner the milled materials from such roads only contain crushed rock and the materials could be used in new SMA pavements.

4.1 QUALITY OF SMA WITH RAP

The described procedure has been tried on a main road in the western part of Denmark. Here an old ultra thin pavement was removed before paving an SMA 8. The milled material was kept separate from the normal RAP at the asphalt plant. Because the milled asphalt contain a high amount of asphalt flakes it was necessary to crush the RAP before using it in the new asphalt. One test result from the crushed RAP is shown in figure 4.



Sieve, mm	Result
8	100
5,6	79
4	52
2	37
1	27
0,5	21
0,25	15
0,125	12
0,063	9,9
Bit-%	7,3

Figure 4: Test result, crushed milled RAP

One half of the road was paved with SMA without RAP and the other half with 15 % RAP. The composition of all other components were adjusted to give de same gradation curve, same bitumen content and same volumetric data. Several samples from each half were tested and the results are summarized in table 5. Both the mean values and the standard deviations (figures in brackets) are listed in the table.

Table 5: Test results, SMA 8 with and without RAP

	EN method	Unit	SMA 8	SMA 8 + 15 % RAP
Number of samples	-	-	11	14
Bitumen content	12697-39	%	7,1 (0,2)	7,1 (0,2)
Aggregate density	1097-6	g/cm³	2,765 (0,004)	2,771 (0,004)
Asphalt density (Marshall)	12697-6	g/cm²	2,396 (0,015)	2,395 (0,014)
Marshall air void	12697-8	%	2,8 (0,6)	3,0 (0,6)
Voids in mineral aggregate (VMA)	12697-8	%	19,5 (0,6)	19,7 (0,6)
Voids filled with bitumen (VFB)	12697-8	%	85,8 (2,8)	84,6 (2,7)
Gradation curve 11,2 mm	12697-2	%	100 (0)	100 (0)
8,0 mm			96 (1)	97 (1)
5,6 mm			62 (4)	60 (2)
4,0 mm			43 (5)	40 (2)
2,0 mm			25 (3)	25 (1)
1,0 mm			18 (2)	18 (1)
0,5 mm			15 (2)	15 (1)
0,25 mm			12 (1)	12 (1)
0,125 mm			10 (1)	10 (1)
0,063 mm			8,0 (1,2)	7,8 (0,5)

Standard deviations are listed in brackets.

The test results show that the two mixes with and without RAP are almost identical and the standard deviations on the different test parameters are at least as good with RAP as without RAP.

Drill cores have been taken in both pavements and the results are summarized in table 6. Also these results show that two laid mixes have nearly identical data.

Table 6: Results from drill cores, SMA 8 with and without RAP

	EN method	Unit	SMA 8	SMA 8 + 15 % RAP
Number of cores	-	-	80	106
Air void Mean		%	4,8	5,0
Standard deviation		%	1,4	1,4
Compaction degree with reference to Marshall asphalt density				
Mean		%	98,1	98,6
Standard deviation		%	1,6	1,4
Thickness, Mean		cm	2,6	2,5
Standard deviation		cm	0,2	0,2

One sample from each mix was tested in more details. The bitumen was extracted and penetration and R&B were measured on the bitumen. The samples were compacted in a roller segment compactor using vertical sliding plates according to EN 12697-33. After one week the samples were tested in wheel track equipment at 50 °C and 20.000 passes (EN 12697-22). The only deviation from the standard is that the specimens have been tested water instead of air. Finally 6 Marshall specimens were prepared with 2 x 30 blows. 3 of them were soaked with water and conditioned with 3 frost/thaw cycles, 16 hours at -18 °C and 8 hours at 60 °C. The 3 others did not undergo any treatment. After conditioning the 3 specimens indirect tensile strength was measured at 5 °C on all 6 specimens (EN 12697-23). A strength ratio is calculated in percent as the ratio between conditioned and unconditioned specimens. All results are written in table 7. The wheel track test is illustrated in figure 5.

Table 7: Extended tests on SMA 8 with and without RAP

	EN method	Unit	SMA 8	SMA 8 + 15 % RAP
Penetration	1426	1/10 mm	59	51
Softening point, R&B	1427	°C	51,4	53,6
Wheel track test, 50 °C	12697-22			
Depth at 20.000 passes		mm	6,03	4,38
Trackrate (10.000-20.000)		mm/1000	0,23	0,14
Indirect tensile test	12697-23			
Unconditioned specimens, mean		kPa	1531	1516
Std.dev.		kPa	120	127
Conditioned specimens, mean		kPa	1602	1856
Std.dev.		kPa	231	21
Strength ratio		%	105	122

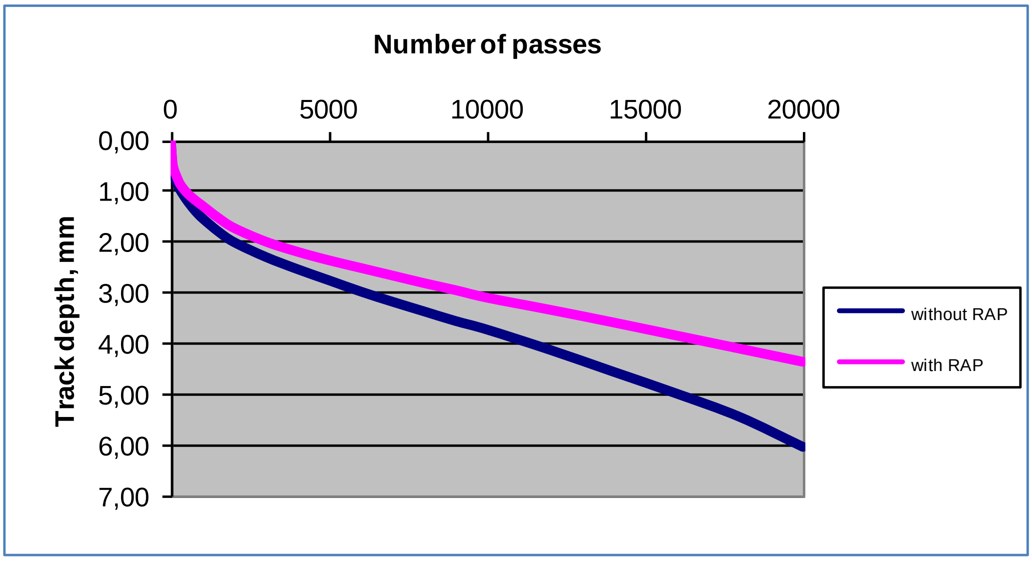


Figure 5: **Wheel track test, SMA 8 with and without RAP**

From the results it can be concluded that RAP does not have any negative influence on a SMA 8. The rut resistance is at least as good or better with RAP as without RAP and the water sensitivity is the same. The ratio calculated on the conditioned specimens is higher than 100 %. A reason for this could be that the added cement has reacted with the water in the conditioning procedure and enhanced the adhesion. The paving crew could not feel any difference which is also reflected in similar compaction degrees and air voids. If they should choose between the two they preferred the mix with RAP.

5 PERSPECTIVES

The tests have shown that RAP does not have any negative effects on asphalt mixes if the specifications for bitumen and aggregates are fulfilled. When producing wearing course of high quality with RAP this has to be of the same high quality as the virgin materials. To control this RAP has to be separated in different qualities and the correct type of RAP has to be used in the different asphalt mixes. In this way the amount of recycling could be increased and the consumption of new bitumen and aggregates will decrease. All Danish asphalt contractors are changing procedure for collecting RAP and all quality data are forwarded to the Danish Road authorities so RAP could be used to a much higher extend. An additional consequence is lower energy consumption for bitumen and aggregate production and less CO_2 will be emitted.

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