UNLOCKING THE FULL POTENTIAL OF RECLAIMED ASPHALT PAVEMENT (RAP) – HIGH QUALITY ASPHALT COURSES INCORPORATING MORE THAN 90% RAP; A CASE STUDY

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ABSTRACT

It is widely accepted that reuse of RAP in the construction of hot mix asphalt is environmentally friendly and also economically beneficial. Addition rates vary from country to country and depending on mix design and existing hard ware but very rarely exceed 50wt% in the final mix.
This paper describes a case study about a mix design incorporating more than 90% RAP. This mix meets German standards for a wearing course subjected to high traffic loads. An area of 3850 m2 aged asphalt concrete wearing course is milled off. Binder content and mineral composition of the RAP coming from a selected road surface is analyzed. The grading curve of the minerals inside the RAP is inspected. Adjustments with virgin aggregate are calculated to generate a final grading curve that meets specification and to accommodate for slightly higher binder content due to rejuvenator addition. Based on the properties of the extracted bitumen proper rejuvenator dosage is calculated as well.
The RAP is heated in a newly designed heating drum and then transferred into a 3t batch mixer. In the mixing process the calculated mineral adjustment is added and homogeneously mixed in together with a hydrocarbon reactivator compound. This compound rejuvenates the aged binder and also adjusts modulus to a desired target level. Finally the mix was successfully paved on exactly the site the RAP came from.

Keywords: Recycling, high RAP content, high quality application, hydrocarbon reactivator compound

1. INTRODUCTION

In pre-industrial times mankind was used to recycle all kinds of materials, simply because of scarce resources. As societies developed more waste occurred and in the second half of the 20th century many industrialised nations were forced by overflowing landfills to recognize that resources were and are discarded at an unsustainably high level. The energy crisis in the 1970's motivated first programmes to collect and reuse energy intense products such as Aluminium and other metals. Increasing pollution of the environment created new awareness which quickly added paper, glass and many other products to the list. Today there is a high but still growing awareness that resources need to be conserved. Governments incentivise collection and recycling systems. Waste material management, sorting, trading and reuse have become a viable and often very profitable business. In addition to recycling many countries motivate campaigns to actually avoid creation of waste.
The use of aged asphalt torn up from roads was treated analogue to these developments. By today discarding asphalt in landfills has fortunately diminished to a rare exception. In fact, asphalt has probably become one of the few construction materials that in some countries, e.g. Germany, is almost fully recycled.
At first glance the situation would appear to be satisfactory and well under control. There are numerous countries where apparently 100 % of asphalt that is removed from streets and other surfaces is re-used. However, in almost all cases this asphalt is recycled at very low levels of economic value. Unbound asphalt granulate is used to reinforce road shoulders, mixed into minerals for road bases and to construct simple rural gravel roadways. If used in hot mix asphalt technical regulations most often restrict use to base courses and other low value applications.
There are exceptions, but at present use of recycled asphalt is mostly focusing on the mineral content of the material. The primary motivation is to utilize the volume and to lower input cost.
In many countries current technical practice and prohibiting technical regulations prevent to recover the full value inherent in recycled asphalt.
Looking at typical asphalt designs the biggest cost factor in a mix is bitumen. The second most expensive material inside RAP is coarse aggregate, especially in wearing courses where high quality aggregates are used. Present practices can be improved to better use these materials.
This paper describes a technology that makes full use of the resources inherent in RAP.

2. Technical challenges for hot mix containing high levels of RAP

2.1. Milling and stockpiling of RAP

The purpose of this paper is to describe and explain the production of hot mix asphalt exclusively from RAP without making compromises on performance of such asphalt versus hot mix asphalt produced from virgin material.
Following the old wisdom "garbage in equals garbage out" it must be emphasized that RAP is to be treated as a valuable source of raw material right from the point where the decision is made that an asphalt surface has to be removed. Road constructions that are designed and built in layers should be milled layer by layer. These layers contain mineral aggregates of different grades and often also different bitumen. Especially in wearing courses selected mineral aggregates of high value are used. If milled together with deeper layers the RAP will be "contaminated" with aggregates of lesser value that e.g. would not pass the criteria for PSV and thus cannot be used in a wearing course again. That means the RAP will automatically "devalue" because they will now end up in binder or base courses.
Equal care should be applied for processing and stockpiling of RAP. An excellent description of best practice can be found in the Technical Recommendations for Highways, TRH 21:2009 published by SABITA [1]. Properly processed, stockpiled and analysed RAP is a non negotiable prerequisite for the use of very high RAP levels or even asphalt production exclusively from RAP.
In Germany it is required to draw one sample per 500 tons of material for analysis whereat analysis must cover: Binder content, Softening point and sieving of mineral aggregates [2].

2.2. Mixing plant technology

High percentages of RAP in a mix make it absolutely necessary to ensure that the binder contained in RAP is fully melted. In mixes where virgin materials are added this binder must perfectly commingle with the newly added binder. A good indication is that binders are deemed to be easily pumpable in liquid form at a temperature approx. 70-80 °C above their softening point. At this temperature they are also liquid enough for homogenisation of RAP binder with virgin binder or rejuvenants in the mixing process. To influence the properties of the resulting binder in a high RAP mix the virgin binder is chosen to compensate for aging and hardening that almost always is found in the binder contained in RAP. This is not only necessary for the in situ mixing of paving grade binder with binder in RAP. In e.g. Germany RAP is also allowed for mixes that by classification require polymer modified bitumen. In order to accommodate the binder inside RAP the virgin bitumen is modified at higher levels than normal, in other words the binder is deliberately "overmodified".

Proper commingling is a function of temperature and mixing time, but it must be emphasised that without introduction of sufficient heat energy into RAP mixing time cannot compensate for that effect.
Any existing asphalt mixing plant can be run with RAP. But without special plant modifications the RAP content that can be used without impairing asphalt quality or creating emissions beyond legal limits is very low and usually ends at 30 % maximum.
In batch plants the possibility of transferring heat from superheated virgin aggregates finds its limits at approx. 30 %. A phenomenon that needs strict observation is spontaneous expansion of water contained in RAP. Conventional drum mixing plants have the problem that the heating flame and very hot gases come into direct contact with the binder contained in RAP. This contact damages the binder and some of it is even incinerated.
Special equipment like twin dryer drums or double barrel drum mixing plants are especially designed to accommodate high levels of RAP and can push the possible addition of RAP to hot mix beyond the 50 % level [3].
A good method to control how well both heat transfer and mixing time are determined correctly is to do trial mixes without addition of virgin binder and filler. This method is very simple to run in a batch plant. The RAP dosage chosen for a mix is introduced to the mixer together with the coarse aggregates according to mix design. The pugmill is then set to a mixing time deemed appropriate. One batch should be discarded immediately; it could be influenced by residual material in the plant. The second batch is then discharged into the shovel of the front end loader of the plant. The material is then dropped on an even surface and spread out. Then two controls are mixed in the same way, one batch with 10 sec. more mixing time and one with 10 sec. less. A simple visual inspection will show how much of the RAP binder has melted and was transferred onto the virgin aggregate.

Figure 1: 25 % RAP, mixed with superheated light coloured virgin aggregate
The visible difference in colour of the batches can be used to assess a mixing time to achieve good commingling of RAP binder with virgin binder

3. Moving from high levels of RAP to full recycling in the federal state Hamburg in Germany

3.1. Regulatory environment for hot mix containing high levels of RAP

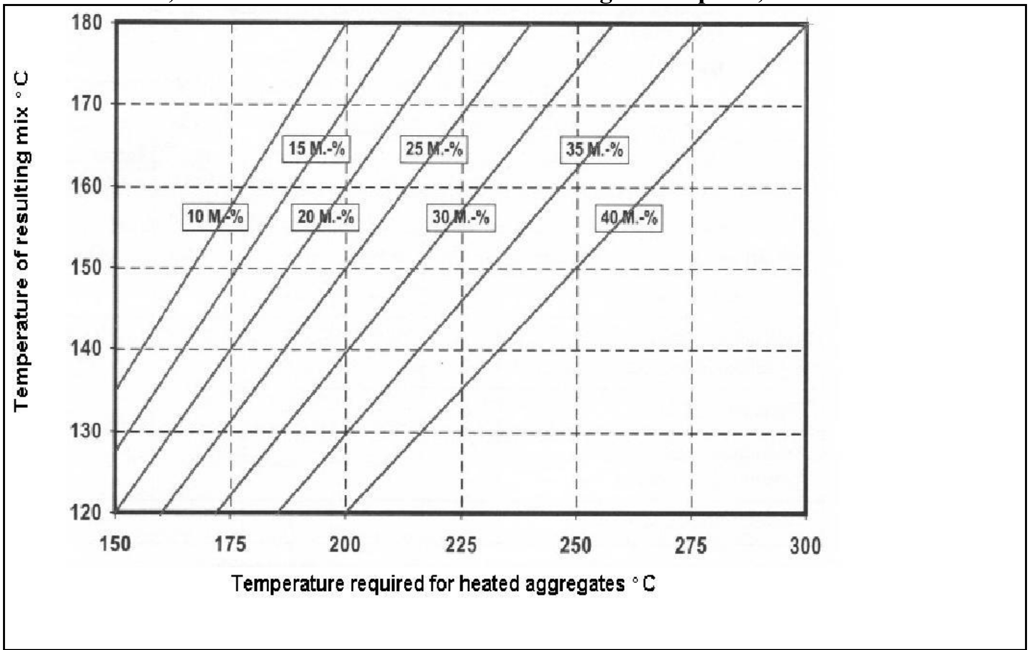
Until 1996 the use of recycled asphalt was only regulated via the technical rules issued by the Forschungsgesellschaft für Straßen- und Verkehrswesen (FGSV). FGSV is a joint body of government, industry and academia that develops and institutes technical recommendations, manuals and specifications for road infrastructure. Two documents contain important sections concerning the use of RAP:

- Merkblatt für die Erhaltung von Asphaltstraßen, Teil Bauliche Maßnahmen, Wiederverwendung von Asphalt, 1985
- Merkblatt für die Lieferung von Ausbauasphalt, 1990 - M VAG 1993

The first guideline covers the upkeep and maintenance of asphalt roads and contains a special section of construction involving RAP. It was issued 1985. The second document focuses on the RAP itself.
In 1996 Germany issued a new federal law. It is called Kreislaufwirtschafts- und Abfallgesetz (KrW-/AbfG). This law was launched to move the national economy towards avoidance of waste and re-use of natural resources and raw materials. For road building the KrW-/AbfG and its subsequent decrees require that wherever possible alternative or recycled materials have to be preferred over any materials that deplete natural resources. All materials have to be reintroduced into the cycle of materials according to their specific properties. This very clearly means that asphalt produced with or from RAP that performs equal to an asphalt exclusively made from new materials must get preference.

Until 2001 the regulatory documents only covered quality requirements on homogeneity of RAP and the binder contained in RAP (mainly its hardness). It was simply understated that the mineral aggregates used in asphalt were already quality controlled at first use.
RAP was mainly produced by deep milling or by taking up the full asphalt package in large broken pieces. Such RAP is considered to be inhomogeneous and can therefore only be used in base layers.
A technical specification for RAP [4] and a manual for handling and use of RAP [5] contain the framework that enables the use of selectively milled RAP in either binder or wearing courses. In 2006 the specifications were updated to be synchronized with the technical specifications for mineral aggregates.
From the beginning of 2009 specifications were harmonized with the European Norms (DIN EN 13108). Use of RAP is now part of the highest level of national specifications.
Today three documents containing specifications govern the use of RAP.
TL Asphalt-StB 07 is allowing use of RAP for all asphalt designs with the exception of porous asphalt (PA). It regulates composition of mixes and quality requirements relative to the different mix design categories. All quality requirements are universal; they encompass mixes that contain RAP. An important issue is regulated in section 3.1.1 of TL Asphalt-StB 07. The softening point of an asphalt mix containing RAP has to meet the requirements of the binder specified in the call for bids. To accommodate hardened binder contained in RAP it is only allowed to use virgin bitumen that is one grade softer than the specified bitumen. The softest grade allowed is a 70/100 PEN paving grade binder.
ZTV Asphalt-StB 07 contains another important rule for binder in mix formulated with RAP. The softening point R&B of a recovered binder from site control after paving is not allowed to exceed the softening point stated in the suitability test fort he mix design
The manual M WA 2009 [5] contains helpful practical information.

Table 1: Required temperature for heated aggregates in °C for addition of dry RAP at levels between 10 and 40 %
Source: FGSV, Merkblatt für die Wiederverwendung von Asphalt, Köln 2009



This only deals with addition of dry RAP. Table 1 shows how to correct for moisture content

Table 2: Amount of temperature increase needed to correct for water content in RAP
The grey area marks the area that is considered critical
Source: FGSV, Merkblatt für die Wiederverwendung von Asphalt, Köln 2009

	Water content in RAP [%]					
	1	**2**	**3**	**4**	**5**	**6**
RAP [%]	**Temperature correction [°C]**					
10	4	8	12	16	20	24
15	6	12	18	24	30	36
20	8	16	24	32	40	48
25	10	20	30	40	50	60
30	12	24				
35	14	28				
40	16	32				

Amongst a host of valuable information it also states the maximum RAP capabilities of different types of mixing plants. As there are virtually no drum mixing plants in Germany this list only refers to batch mixing plants:

- Heat transfer via superheated aggregates, pugmill addition: 30 %
- Heat transfer via superheated aggregates, continuous addition of RAP to hot elevator: 40 %
- RAP heating together with aggregates (addition to drying drum via centre ring or special throwing belt): 40 %
- RAP heating in separate apparatus (Parallel drum): 100 %

Even if the RAP is dry (preferably by storage under roof) it is most often not possible to add as much RAP as the technical equipment of the plants would allow. The reason for this shortfall is that the bitumen contained in RAP is often severely aged. This ageing manifests itself in binder hardening, the needle penetration drops and the softening point increases. Bitumen ages by:

- Oxidation
  Reaction of bitumen with oxygen
- Volatilisation
  Evaporation of lighter binder constituents
- Polymerisation
  Combination of like molecules to form larger molecules, resulting in progressive binder hardening
- Separation
  Removal of bitumen constituents in selective absorption by some porous mineral aggregates

The central value in Germany for evaluating bitumen characteristics against contract specification is the softening point that is determined by the Ring and Ball (R&B) method. Therefore all specifications that deal with RAP also focus on this value. The present specifications only allow adjustment of the softening point by in situ blending with the total addition level of RAP and by using softer virgin bitumen for blending in the mixer. But use of softer binder is capped at one grade above specified binder.
This factually leads to a recycling quote far below technical capability and also far below the intent of the German law for waist avoidance and recycling (KrW-/AbfG).
To reach better compliance with the recycling law and also to further improve the sustainability of asphalt pavements it is necessary to further evolve specifications and to explore new technologies as well.

3.2. *From Saseler Weg to Pollhornweg - case studies about full recycling of an asphalt wearing course*

Excellent results coming from laboratory research on regeneration of RAP with highly defined flux oil for use in base courses as well as in SMA applications have prompted the Hamburg authority „Behörde für Stadtentwicklung und Umwelt“(BSU) to use such products in a full scale trial. The goal of this trial was to validate the laboratory findings in a full depth asphalt construction with three layers
The trial site „Saseler Weg“ was used to use hot mix asphalt containing high levels of RAP where the softening point of the resulting binder of the mix was adjusted via the addition of highly defined flux oil. This viscous product is produced from the high boiling fraction of recycled engine oils. All light components are removed by destillative process, the product is de-metallized and has a flashpoint > 220 °C.
For this trial the target softening point of 52-56 °C was targeted. It was to be achieved by using 50/70 PEN virgin binder, RAP and flux oil. The softening point found in the different RAP selected for the trial ranged from 62,4 °C to 82,6 °C. With flux oil it was possible to use 40-50 % of RAP. For the control it was necessary to use a softer bitumen grade and the addition level of RAP had to be reduced in order to meet the targeted softening point range.

Table 3: Comparative data on asphalt mixes used in the Saseler Weg trial
Source: Behörde für Stadtentwicklung und Umwelt, Hamburg 2010

	Section I with flux oil AC 22 T Hmb	**Section II without flux oil AC 22 T Hmb**	**Section I with flux oil AC 16 B N**	**Section II without flux oil AC 16 B N**	**Section I with flux oil AC 8 D N**	**Section II without flux oil AC 8 D N**
RAP content	50 %	25 %	40 %	30 %	40 %	40%
Binder content from RAP	2,0 %	1,1 %	2,20 %	1,50 %	2,2 %	2,2 %
Virgin binder	0,6 % (B50/70)	2,8 % (B70/100)	1,1 % (B50/70)	2,7 % (B70/100)	3,8 % (B50/70)	4,2 % (B70/100)
Fluxoil	1,4 %	-	0,9 %	-	0,4 %	-
Resulting binder content	4,0 %	3,9 %	4,2 %	4,2 %	6,4 %	6,4 %
R&B RAP binder	82,6 °C	67,6 °C	73,2 °C	63,7 °C	62,4 °C	62,4 °C
R&B virgin binder	52,0 °C	46,0 °C	52,0 °C	45,0 °C	52,0 °C	46,5 °C
R&B targeted for resulting binder	52,0 °C	52,2 °C	52,0 °C	51,8 °C	52,0 °C	52,0 °C
R&B found in mix	55,0 °C	57,2 °C	56,2 °C	56,8 °C	53,0 °C	55,0 °C

The comparative performance testing proved that the high RAP mix with flux oil was performing equal or better than the control. The Thermal Stress Restrained Specimen Test (TSRT) delivered clear results that the asphalt mixed with high RAP content and flux oil has a significantly better cold temperature performance that the control.

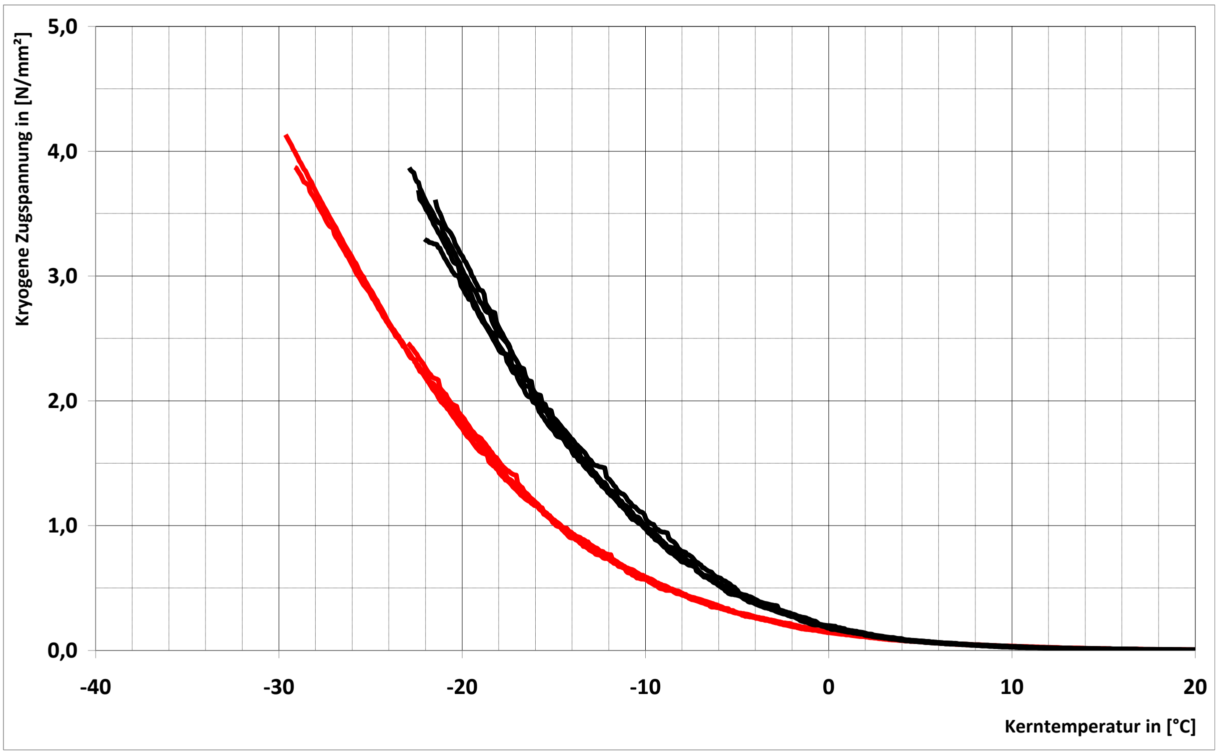


Figure 2: TSRT test data for binder layer mixes used in the Saseler Weg trial
Source: Behörde für Stadtentwicklung und Umwelt, Hamburg 2010

The red curve in Figure 2 displays that the binder layer mixed with RAP and flux oil has a significantly better performance than the control (black curve). The fluxed mix can be cooled 4 K lower than the control and requires a slightly higher cryogenic tension for breaking.
The TSRT tests for the wearing course are almost identical to the binder layer. The base course also shows an improvement for the fluxed material but it is less pronounced.

The very positive practical results obtained on the Saseler Weg trial site as well as the convincing findings from the analytics performed on the mix used during the trial have proven that rejuvenation of significantly aged binders in RAP is not only possible in an laboratory environment. The upscale to plant level was realised without any problems and has shown that aged binder can be fully regenerated, enabling the use of much higher RAP levels than present specifications would allow.
A logical question arising from above work is if it is possible to not only use 50 % RAP but to produce new high quality hot mix asphalt exclusively from RAP and a rejuvenator system.
In 2010 it was tried for the first time on a public road in Germany to produce an asphalt wearing course almost exclusively from RAP. It was decided to select a road with a significantly aged wearing course. To make the trial very obvious the wearing course was to be removed, taken to a mixing plant and to be repaved at the very same site it was milled from. The Pollhornweg site was chosen, it is located in a commercial area in the port of Hamburg. The road is very straight and because it is subjected to a high number of high axle loads it was found to be ideal for this trial. The asphalt surface had reached the end of its life, displaying cracks, opening of the middle seam, loss of aggregates and many repairs. Most of the surface was a 11 mm asphalt concrete. Goal of the trial was to prove that by using a rejuvenator system containing a rejuvenator component and a Warm Asphalt additive together with this RAP the wearing course could be fully recycled and meet the performance specifications for a road of this category.

Different to the Saseler Weg trial the rejuvenator was blended with a Fischer Tropsch Wax. Previous trials on private properties had proven this combination to be very effective. The second additive is not only improving the asphalt quality up and above what can be reached with flux oil, it also is necessary to ensure that the mix temperature can be kept low enough to not produce technical or environmental problems with the exhaust from the mixing plant. Heating RAP to a suitable temperature for use in a mix made up exclusively from RAP can produce a score of problems, even in specialized equipment such as parallel drums. When the binder contained in RAP is exposed to excessive heat there will almost always be a problem with a too high rate of carbon based emissions and the already aged binder is damaged further. Another problem is that at high temperatures bituminous vapours and aerosols are generated that can cause irreversible clogging of the baghouse filters. Such clogged filters can only be discarded and replaced. Running the mix at warm mix temperatures solves both problems in most plants. The combination of wax and flux oil also produces an extremely workable mix, even at reduced temperatures.

The recycled wearing course was paved on Sept. 25th 2010. In the week prior to paving operation the suitability test for the mix design was performed. To meet an approved contemporary mix design for an 11mm asphalt concrete according to valid Hamburg specifications the RAP taken from site was mixed with the rejuvenator wax combination called Storbit. To meet the mix design small amounts of another RAP had to be added. As the Storbit will increase the binder content in the mix it was inevitable to add small amounts of virgin aggregates in order not to exceed the binder content specified for the chosen mix design.
Manufacture of the mix was performed without any problems. The two different RAP components and the new aggregate were dosed via feeder bins according to mix design onto a belt leading into the parallel drum.

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Kornzusammensetzung des Gesteinskörnungsgemisches

mm	Rückstand	Durchgang	M.-%
> 45,00			
45,00			
31,50			
22,40			
16,00		100,0	grobe GK 62,2
11,20	1,5	98,5	
8,00	14,5	84,0	
5,60	17,5	66,5	
2,00	28,7	37,8	
1,00	8,9	28,9	feine GK 28,8
0,25	13,1	15,8	
0,125	4,4	11,4	
0,063	2,4	9,0	
< 0,063	9,0		Füller

Sieblinienbereich für AC 11 D S 30/45SD2+91% AG

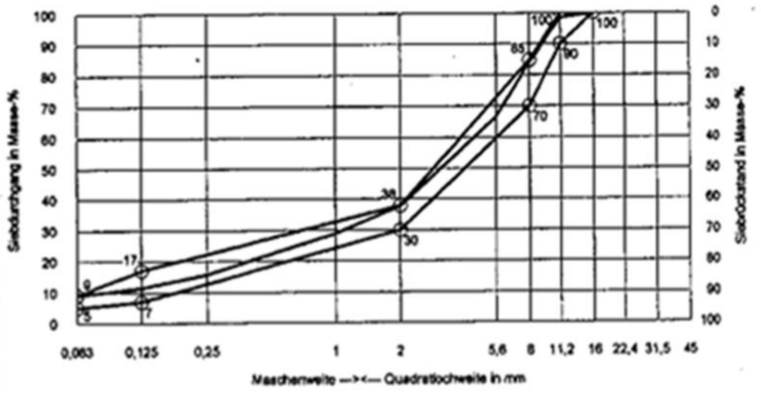

Figure 3: Grading curve for Polhornweg trial
Souce: Rezeptur für Asphaltmischgut, Deutag, Hamburg 2010

Mischguteigenschaften				
		Mischgut-zusammensetzung	Sollwert	
			min	max
Rohdichte	Mg/m³	2,499		
Raumdichte	Mg/m³	2,427		
Hohlraumgehalt (ber.)	Vol.-%	2,9	2,5	4,5
Hohlraum mit Bindemittel ausgefüllt, HFB	%	81,3		
Proportionale Spurbildungstiefe (60 °C Luftbad / Gummirad)	%	8,8		
Spurbildungstiefe (50 °C Wasserbad / Stahlrad)	mm	3,9		
Verdichtungstemperatur	°C	125,0		

Figure 4: Mix properties Polhornweg trial
Source: Rezeptur für Asphaltmischgut, Deutag, Hamburg 2010

In the parallel drum the material was carefully heated to 160 °C and transferred into the pugmill where the Storbit was added during the mixing process. The mix was sampled at plant with 160 °C, after a short transfer the material reached the site and 150 °C in the paver. As ambient temperatures increased the mix temperature was dropped by approx. 10 °C. The mix composition showed no deviation against the suitability test and complied with the requirements specified for Hamburg [6]. The properties of the paved layer also met requirements. All cores were tested for adhesion between layers. The sheer force trial results met and exceeded the required standards.

Interesting to note is that the AC mixed from the old wearing course performed exceedingly well in the wheel tracking test (see Fig. 4). This test normally is not required for such mix designs. Experience has it that a virgin mix design with 50/70 paving grade binder would fail the test at approx. 12500 cycles. This mix however has a wheel track after 20.000 cycles of 3,9 mm. This value is almost competitive to a SMA 0/8 with PEN 45 PmB. The specified value for Hamburg such 8mm SMA is 3,5 mm [6].

Summary

The results of pre paving examinations, testing against specification as well as performance testing, on and around the Pollhornweg trial show that with this new technology a development is kicked off that clearly has the potential to produce asphalt from almost 100% RAP that meets the current performance criteria for asphalt mixes even of high load categories. The aged binder inside the RAP can be rejuvenated with relatively small amounts of additives. The flux component selected for these trials is also a recycling product. It needs to be emphasised that this product has a good track record and is specifically composed and produced for use in asphalt. It meets high safety health and environmental standards and id free of aromatics. Surely there are other products in the market but they need to be carefully inspected if they are suitable for use. Generally the term „flux oil“ unfortunately has often bad connotations. All too often old engine oil or even more dubious substances get used „straight from the collection drum“.

Storbit replenishes the bitumen components that disappeared from the bitumen in RAP by way of the ageing mechanisms described in this paper. Bitumen can be completely rejuvenated. Combined with all other necessary processes like selective milling, proper stockpile management, constant analysis and monitoring of RAP components and properties this technology opens the way to use RAP on the highest possible level of value generation.

STORIMPEX, the producer of the additive combination has not only more than 20 years experience with use of highly defined flux oils in asphalt. Their expertise was combined with Sasol’s technology for asphalt additives. Rejuvenation technology is not only about adding a „miracle substance“ to RAP. Designing mixes with high RAP content also involves a high level of understanding and controlling input materials. Going to RAP levels far above 50 % also requires suitable plant hardware. Only few existing plants are already equipped in a way that they can handle fully recycled asphalt without the need for plant modification or significant investment.
Very obviously the savings produced from reuse of aggregates and bitumen are significant and can more than amortise investment into new technology.

The authors thank the Hafen Port Authority (HPA) of Hamburg for enabling the Polhornweg trial. Thanks also go to the BSU as local authority for sharing results obtained by the trial work.
BSU signals to proceed with this technology in 2011. After positive evaluation the specifications of the federal state of Hamburg will be opened to enable regular use of the technology.

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