Hot recycling of Asphalt: experiences in Flanders and the Netherlands

W. Van den bergh
(Artesis University Antwerpen)

M.F.C. van de Ven
Corresponding author: m.f.c.vandeven@tudelft.nl)
(Delft University of Technology)

Abstract

Reclaimed asphalt (RA), also called Recycling Asphalt Pavement (RAP) is used extensively in the Netherlands and Flanders since the 1980s. Economical and political reasons can be formulated to explain developments. The use of RA is given the economical value in most cases seen as an advantage, since RA has a very low cost price compared to virgin materials. For example the investment in parallel drums in the Netherlands was no problem at all in the decision to scale up the use of RA. Hot reuse of RA makes it possible to replace part of the expensive virgin bitumen by the aged bitumen in the RA. This results in a high level recycling application. Of course the question arises if re-use of RA in hot mix will influence the quality of the end product: asphalt concrete with and without RA will have to fulfill the same functional requirements in the new CE-marking system and standards. In this paper the influence factors of RA on an asphalt mixture and the meaning for the CE-marking requirements are discussed with an example on the role of the retained indirect tensile on the mixture design with RA
With this paper we would like to highlight the discussion on advantages and disadvantages, limitations and potentials of the use of RA.

1. Introduction

There is only limited information available on the influence of addition of RA to a mixture on the properties. In the Netherlands a lot of information is available on initial mechanical properties of mixtures with high percentages of RA (mostly 50%), but no record is really available on the service life. In Flanders (Belgium) RA is used in most asphalt mixtures for base layers, without a scientific validation of the influence of RA on the durability of the mixtures in situ. . The question is raised continuously if the use of AG can influence the quality of the mixture in a negative way. One thing is clear: the production process is becoming much more complicated when using the RA. A composite material is added instead to separately added components.
RA is generated when (part of) the pavement is milled or broken up. Recycling RA can be a nice closed circle: the material was asphalt concrete before and the milled material is again re-used in asphalt concrete at the highest possible recycling level. Recycling with low amounts of RA (up to 20%) was for many years common practice and quite simple, because it is mostly done with cold addition of the RA in the pug mill for a batch plant mixer or halfway the drum mixer. However, recycling with high amounts of RAP (50% and more) and producing high quality asphalt mixture is a technological challenge. RA contains aged bitumen, has not always a homogeneous composition and impurities can be part of it. It is then very difficult to predict the material properties after production and compaction. The same holds for the quality control of mixtures with RA. We need to know the possible consequences of the use of RA. The volumetric

parameters of the mixture can change and probably show larger deviations than normal. The composed binder contains partly aged (oxidized) bitumen and the ratio with the virgin bitumen is based on the so called log penetration rule. The angularity of the aggregates is not only dependent of the primary aggregates; the compactibility can be quite different with higher percentages of RA. Also the logistics of an RA materials stream is a complex and economical important process.
Nevertheless, the use of RA as a basic component in hot mix asphalt has become common practice. This is because for society and environment, the use of RA means less use of primary components (stone, sand, filler and bitumen) and a reduction in the transport and the production of primary raw materials. In this context, the government has the responsibility to stimulate and regulate the use of RA. For the asphalt plant this means that production of asphalt mixtures with RA is in most cases economic competitive with mixtures with virgin components [1]. Additional cost for selective storage (sometimes under roof), breaking, sieving, RA-analyse, extra controls, etc. should be included in a comparison. Depending on the role of the government this determines if use of RA is economically viable.

Of course it is very important to make sure that reuse of RA will result in a positive environmental- and health situation. For this reason the reuse of tar contaminated RA is forbidden in the Netherlands and Flanders since 1990. This material should be treated separately, in a cold recycling process.

2. Hot recycling of Reclaimed Asphalt

Developments since 1970…

The oil crisis in 1973 stimulated efforts to find alternative methods and materials to produce asphalt mixtures. One possibility was of course the recycling of old asphalt mixture. Many projects in the USA, Netherlands, Japan and Great Britain were started with the ambition to find the best process to reuse RA. In general three basic methods were investigated: recycling in situ, recycling in the asphalt plant and recycling in combination with cement. This last one is normally spoken used in a cement bound foundation layer and isn't discussed here. In situ hot or cold recycling was not successful in both Flanders and the Netherlands. Since the first use of RA in hot mixtures in the 1980s, the application has increased continuously. In Flanders asphalt mixture produced in a so-called COPRO-certified asphalt plant gets a COPRO-quality marking when quality requirements are fulfilled. This quality marking is always necessary for government contracts. In 1997 in Belgium 600.000 tons of asphalt mixture with RA was used on a total of 2,7 million tons. In 2005 this practice increased up to 600.000 tons in 1,6 million tons asphalt concrete, at a total of 3,5 million tons of asphalt, so the amount of recycling was (600.000/1.600.000)*100 = 37,5 %. Figures of EAPA [20] indicate that 1.300.000 tons of RA is avalaible for recycling of which 50 % is used in hot mix asphalt and that 38% of the hot mixes are containing RA. However, one expects that the total amount of RA is about 2 million tons per year estimated on a total production of new asphalt mixtures in Belgium of 4,5 million tons.Nevertheless, RA is predominantly used for cold recycling in cement bound or unbound foundation layers . In 2009 Flanders counts 20 asphalt plants, on a total of 42 for Belgium, of which 11 equipped with hot preheat feed and 5 with a cold feed facility; in Flanders 16 plants are COPRO-certified and in Wallone 8 of 22 asfalt plants[2].
In the Netherlands almost all RA is reused in hot mix asphalt mixtures. In 2007 [20] approximately 3,5 million tons of RA was used on a total hot mix production of 10 million tons. In the Netherlands almost all 40 asphalt plants have the possibility to preheat the RA. Because of the fact that almost all plants are batch plants, a parallel drum is used to preheat the RA to a maximum of 130 to 150 C, before it is added in the pug mill. In this way all Dutch manufacturers are able to produce 50% RA in a hot mix asphalt mixture. The amount of RA and the

requirements to use them are fully specified in the Dutch standards (RAW). In this standard it is allowed for most mixtures to add up to 50 % of RA to the hot mixture to be produced. Assuming that almost all mixtures were produced with 50% RA, approximately 6 million tons of hot mixtures were produced with 50% RA in 2007.

Acceptation and registration

In Flanders and also in the Netherlands RA is recognized as a secondary material [3]. Studies showed that RA fulfills the requirements for materials to be used in contact with groundwater carrying soils[4]. Criteria used are concentrations of hazardous materials and concentrations of leaking metals. The concentration of PACs (Polyaromatic hydrocarbons) is limited to such an amount that tar containing asphalt is not allowed for RA hot recycling
For production control extra testing on and continuous monitoring of RA is needed. RA has to comply with the standard EN 13108-8: Reclaimed asphalt. For Belgium extra requirements are regulated in TRA13 [5]. This document is concurrent with EN13108-8.
In a first step the old asphalt layer is visually inspected on homogeneity and further analyzed via tests on cores. The composition, stone type, thickness, possible impurities (a.o. SAMI and tar) and binder characteristics (content, penetration, type of bitumen) are determined. Each homogeneous section will in this way be characterized so selective milling will result in homogeneous RA. RA with a penetration lower than 10 is not accepted for hot recycling. The same counts for RA with asbestos fibres. All RA at the asphalt plant must have the discussed information. Each group of RA is seperately stockpiled In some cases of small quantities or different types of RA are mixed before testing. From the final stockpile the properties are determined for each 10000 tons of production: binder content, penetration and gradation. These proprties are determined in the asphalt plant laboratory and checked by an external lab. Requirements for homogeneous RA in Flanders are given in table 1.

Table 1: Requierements for homogeneous reclaimed asphalt in Flanders

Parameter	**Tolerance for each individual test**
course <2mm	+/- 10%
Filler < 0,063mm	+/- 3%
Binder content	+/- 1%
Penetration	+/- 10 mm/10

In the Netherlands requirements are posed to the RA when it is a continously available component in the production process [19]. Regular checks need to be done to have the material accepted as homogeneous RA. At each check 5 samples of each 2,5 kg are taken from the RA heap. The RA is considered homogeneous in case the standarddeviations calculated over the results of the 5 samples satisfy the requirements shown in table 2.

Table 2. Requirements for homogeneous RA in the Netherlands [19]

	Maximum standard deviation for 5 samples at percentage reuse of RA of:	
	≤30	>30
Grading (%):		
passing sieve 11.2[1]	6.5	6.0
passing sieve 5.6[2]	5.5	5.0
passing sieve 2 mm	4.5	4.0
passing sieve 63 µm	1.2	1.0
Bitumen content (%)	0.5	0.4
penetration	5 (0.1 mm)	4 (0.1 mm)

[1] only for surfacing layers of DAC
[2] only for binder- and surfacing layers of DAC

As extra requirements for the regained bitumen of the RA it is stated in the Dutch Standard [19] that the minimum value must be above 10 and the mean value of 5 test results at least 15. In case the RA consists of at least 95 % (m/m) milled porous asphalt, the penetration of the regained bitumen from the RA should be at least 5 per measurement and the mean of 5 measurements at least 10.

Maximal possible amount of RA in hot asphalt mixtures in Flanders

The maximal possible amount of RA in hot asphalt mix is described in the Regional Standard SB250 version 2.1 [6]. The maximal use of RA is expressed as a function of the maximum amount of binder from RA in the final mixture. In base layers a maximum of 50% of bitumen from homogeneous RA, 20% of bitumen from non-homogenous RA, or 10% from GBSM (granulated bitumen shingle material) is allowed in the final mixture. When different RA-categories and/or GSBM are used, the following formula is taken:

Total Bitumen of [%(HE-RA) + 2,5x(%NH-RA) + 5x(%GBSM)] < 50% bitumen in mixture.

The consequence of the formula is that for example with addition of 10% of GBSM, it is not possible to add more bitumen from RA types, because the product of 5*10 =50 is the maximum. RA can be added cold or pre-heated by a parallel drum. When RA is added cold, directly in the mixing unit, the maximum amount of RA to be added is 20% for base layers. When the RA is preheated to at least 110°C (warm addition) the amount of RA can go up to 50%. In this case it is necessary to make use of parallel drum in batch mix plants. For surface layers like Stone Mastic Asphalt (SMA) and porous asphalt (PA) the use of RA is not allowed. An overview of the maximum allowed amounts is given in table 3.

Table 3: Maximal use of RA in Flemish asphalt mixtures according to SB250 v2.1

Maximal amount of RA-bitumen in the composed binder with hot recycling in Flandres					
Asphalt type	Addition of RA; with or without pre-heating (parallel drum)				
	Pre-heating via parallel drum (“hot addition >110 °C”)			without pre-heating (“cold addition”)	
Base-layer AB-3 (AC dense)	(%Hom.) + 2,5x(%NonH.) + 5x (%GBSM) < 50			(%AG) + 4x(%GBSM) < 20	
	Homog.RA	N.Hom.RA	GBSM	RA	GBSM
	50	20	10	20	5
Surface - layer AB1 and AB4 (AC dense)	(%Hom.) + 2,5x(%N..Hom.) < 50			10	0
	Homog.RA	N.Hom.RA	GBSM		
	50	20	0		
SMA and PA	**No RA permitted**				

An important additional requirement for using RA is that the composed bitumen with RA in the final mixture has to fulfill the same requirements as for mixtures with only virgin bitumen in the mixture. Example: when a bitumen with penetration 35/50 is prescribed in the contract then the combined binder of old and new should have a penetration between 35 and 50 according to the log penetration rule. The penetration value of the virgin binder should be chosen such that the combined penetration is between 35 and 50. It is allowed that the lower level is decreased with 5 1/10 penetration. The Flemish Roads Agency rquiere always that the properties of the mixture with RA are at least the properties of the virgin mixture. In this way the requirements for CE-marking are not influenced by the addition of RA.

In the Netherlands the maximum possible amount of RA in mixtures is limited to 50 % RA, so the total mixture. This is valid for all mixtures except Stone Mastic Asphalt and Porous asphalt in which it is not allowed to use RA. For all mixtures with RA the requirement for the combined binder must however satisfy the requirements that the combined binder has a penetration similar to the penetration of the virgin mixture binder, according to the log penetration rule. So it is possible in the dutch context that the bitumen content of the RA can be more than 50% of the total combined bitumen. In the Netherlands it is not allowed to recycle GBSM in asphalt mixtures.

Some typical characteristics of certified RA

In Flanders no official database for RA characterization is available. Some information can be obtained at the MOW (Flemish roads agency) and certifying bodies like COPRO. On the basis of individual registrations an overview was made for 2002 in [7] for 21 different RA-samples. This information was recently updated by Van den bergh [1, 18]. From the results it can be concluded that the mean grading of RA-mixtures remains more or less constant between 2002 and 2007. Figure 1, shows the gradations together with the under- and upper limits. The properties of the bitumen are summarized in table 4.

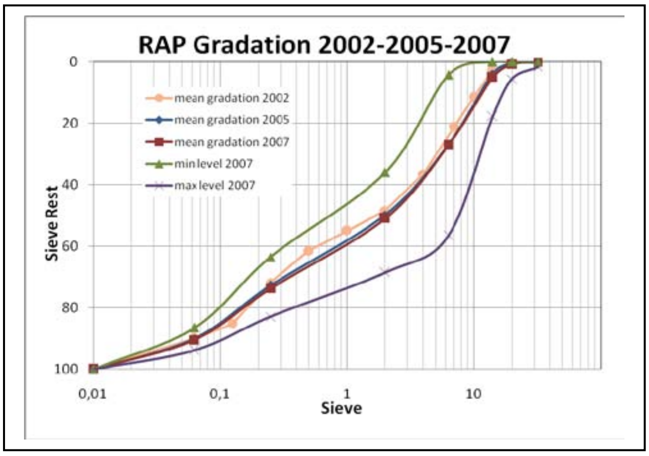

Figure 1: mean RA-grading 2002, 2005 en 2007

Tabel 4: Properties of RA-binders

RA-binder	Binder		% binder (on 100% aggregate)
	Pen [1/10mm]	R&B [°C]	
Mean 2002	27,1	62,3	6,1
St.dev. 2002	5,3	4,4	0,9

Mean 2005	24,4		5,9
St.dev. 2005	6,5		0,8
Mean 2006	18,6		
St.dev. 2006	5,6		
Mean. 2007	18,8		5,6
St.dev. 2007	3,9		0,9

It is not surprising that the grading is more or less constant, because in the survey time the asphalt mixture composition hardly changed in Flanders. For the penetration of the RA-bitumen a clear trend is noticed: the mean value decreased from 27,1 to 18,8 1/10mm. Possible reasons are the use of harder bitumen (to reduce rutting) and delayed maintenance. These results are of course only valid for RA of asphalt plants working under certificate.

3. Influence of RA added to hot mixture on performance

Busschots and De Backer [8] reported an visual inspection campaign on the performance of 37 road sections with RA in 1990's. Four sections showed already damage after 4 years of service; from three of these sections it was know that RA was added cold. In general no loss in performance was observed for asphalt structures with RA in hot mix.
However, as discussed before, use of RA as a secondary component requires careful operation. First of all there is no watertight tracing system (it is not known which asphalt mixture is used in a certain road section) and the recovery of the binder for e.g. modified bitumen is now under discussion. This makes it impossible to determine the exact composition of the binder in the RA. From the previous discussion it becomes also clear that the RA has certain influence on the properties of the final mixture. In the next paragraphs some influence factors will be discussed.

Determination of the characteristics of the components

For optimal mixture design it is necessary not only to know the bulk composition, but also to know the characteristics of the components. The origin and the shape of the aggregates should be known: for example in Flanders it is not permitted to use limestone types in surface layers, round grains can lead to higher rut sensitivity. The filler type in the RA is also important and can hardly be determined visually. What is the stiffening effect of this filler? The effect of regenerated filler in the asphalt mixture is hardly researched. At the Artesis University of Antwerp this subject will be studied the coming years.
Most attention will go to the determination of the characteristics of the binder. Recycling of RA with polymer modified bitumen (PMB) is a different story. How to determine the influence of the aging on the initial properties of the PMB? Is it possible to reuse them based on the log penetration rule? Which mixing temperature needs to be used to get the aged PMB viscous enough for hot recycling, etcetera.
At the moment the properties of the bitumen in RA are determined by the standard extraction- and recovery processes. These processes are normalized e.g. EN12697-1 and 12697-3, but there is a lot of discussion on it.
In 2006 in Belgium the reproducibility of the penetration test of several regained RA-bitumen between external and internal labs was R=12 which was not in accordance to the standard R=0,27*pen. For a mean RA-bitumen this should be approximately 6. For this reason the Belgium certification body COPRO organized a round Robin in 2006 in which 17 Belgian asphalt plants and labs participated. 17 labs performed the penetration test on a virgin penetration grade bitumen, on the same bitumen after an extraction and recovery process, and on a bitumen regained from a unknown RA. The mean pen-value of the virgin bitumen was 36. This value was

also given by the bitumen producer. The R-value according to EN1426 is 3 for the bitumen. The values of the participating laboratories varied between 25 and 44 1/10mm. 9 of the 17 participants did not satisfy the R-requirement of the norm.

Tabel 5: results of the Round Robin test RA Belgium 2006

	Results	Reproducibility
Penetration virgin bitumen 1/10mm	Mean: 36 Interval: 25 – 44	Norm: 3 1/10 mm (EN1426) 9 labs not OK 8 labs OK
Penetration of Recovered virgin bitumen 1/10 mm	Mean: 36 Interval: 25 – 100	Norm: 9,7 1/10 mm 2 labs not OK 13 labs OK
Penetration of recovered RA-binder 1/10 mm	Mean 29 Interval: 8 – 44	Norm: 7,8 1/10 mm 2 labs not OK 13 labs OK

The values of the penetration of the “recovered” virgin bitumen were between 25 and 100. After using these two extreme values as outliers, the mean value of the penetration was again 36. From the resulting 15 participants the norm was fulfilled by 13 labs. It seems that the recovery method and –treatment does not influence the penetration value. One lab used toluene (pen 39), 6 labs used trichloroethylene (pen 35,5; st.dev. 3,3) and 9 labs used methylenechloride (pen 36,6; st.dev. 3,9).
Analysis of the results of the RA-bitumen showed that the reproducibility interval also in this case was too large. A mean value of 29 was found with a minimum of 8 and a maximum of 44. De standard deviation is still 7,8 after rejection of two outliers. It seems that the regaining process of RA-bitumen (with unknown result on beforehand) is much more difficult. Van den bergh [18] preformed DSR-measurements on a number of the binders. The results were compared with the penetration values. From this it was concluded that the regain procedure was done correctly by the laboratories (G* was in line with the calculated penetration according to Saal and Labout [9]). The large differences in pen-values are probably caused by bad execution of the penetration test. Based on the round robin the laboratories have reconsidered their quality system with a decrease of the reproducibility interval as a result.
An analysis of the G* values before and after regaining learned that the bitumen after recovering has a lower G* than before. This becomes more pertinent at 25°C and lower temperatures. The ‘softer’ behaviour is confirmed by a study at Antwerpen college [10] on standard penetration and modified bitumen: the critical low temperature according to the BBR-test of a bitumen after extraction and recovering is lower. Conclusion: a recovered bitumen shows after extraction and recovery a better low-temperature behaviour than in the field. So the method could result in an overestimate of the low temperature properties. However, from this research it became also clear that the centrifuge configuration with methylene as solvent influenced the low-temperature behaviour the least.
So from the experiment with the virgin bitumen it is suggested that the low-temperature properties can be over-estimated and that recovery of RA bitumen gives a larger variation on rheological measurements In case of low-temperature properties for asphalt mixtures with RA(new and recovered) this should be considered carefully.

Retained Indirect Tensile Strength (ITS-R) according to EN 12697-12 en 12697-23

For Flemish asphalt mixtures requirements are given in [6] for the ITS-R value at 15°C as replacement of the Marshalltest characteristics (Stability and Flow). De ITS test is performed on the asphalt mixture at the optimal binder content. This optimal binder content is determined by criteria for the voids content and the voids contents of the aggregates filled with bitumen at three binder contents (b-0,3; b ; b +0,3). For base course mixtures the ITS-R value has to be at least 60% (70% from 2010).
In Flanders hardly any experience was available in 2006 on the ITS-R in general and nothing at all for RA-mixtures. Because this test is an important one in the CE-marking, Artesis Antwerpen University Colleges [1,11] started a research into the influence of RA in a mixture on the ITS-R.
Firstly an AB-3 mixture (an AC with 0/14 grading) was artificial aged to RA (AAAM: artificially aged asphalt mixture). The asphalt mixture was kept in an air ventilated oven during 7 days at 90°C. This ageing is fixed so the binder penetration in the mixture after ageing is comparable to the binder penetration of the same binder type aged by RCAT-Long Term Condition. In this way it was possible to determine both mixture properties and rheological behaviour of the bitumen without the use of recovery techniques. Results indicated that addition of RA gives improved ITS-R values till 80% reuse, at a constant amount of bitumen in the mixture and by using the same virgin bitumen type (B35/50) for the new bitumen to be added. The results even improve (higher ITS-R values) when instead of B35/50 softer bitumen is used resulting in a constant penetration value of the binder in the RA mixture (changing bitumen type according to the logpen-rule: target end value of penetration was 41). The values of all ITS-R results of mixtures with this AAAM up to 80% are above 77,7%, which is the ITS-R value of the reference mixture without RA. A mixture of 100% AAAM had an ITS-R value of 67%. Because an artificial aged mixture was used, all mixtures have the same binder content, grading and basic components. The effect on the ITS-R value is in this case only dependent on the amount of AAAM-bitumen.
In a second phase the bitumen content was changed from 5,0% (in mixture) to 4,7%. By reducing the amount of binder the ITS-R values decrease considerably. The reference mixture without RA has an ITS-R value of 58% and does not satisfy the standard SB250. Addition of RA increases the ITS-R value; however, the ITS-R values stay always below the values determined for a mixture with 5% bitumen, which indicates the relevancy of the binder content. Addition of RA to the mixture increases the ITS with a peak at 65% RA ; after that the ITS reduces again.
In a third phase a rejuvenator was added. Addition of a rejuvenator results in lower ITS values, but the ITS-R values increase. Addition of a rejuvenator increased ITS-R from 80% to 92%. Tests on mixtures with “real” RA show the same tendency: the addition of RA results in higher ITS-R values up to 60%. In the near future research will be done with several types of RA and rejuvenator for the standardization.
Also in a study of the Belgian Road Research Centre [12] in which EME (high modulus asphalt mixture) was used with and without RA (up till 40%), a very high ITS-R was reported (94-115%) independent of the use of the RA.

Mechanical properties; stiffness, rutting and fatigue

In the CE- marking system requirements of importance for pavement design properties like stiffness, fatigue and resistance against permanent deformation are given. In the Netherlands it is required to measure stiffness, fatigue and permanent deformation for dense graded mixtures with or without RA for CE-marking. At this moment, for Flanders stiffness and fatigue aren’t required yet.

When RA is added as a component to a mixture this will influence the material properties. The example of the rejuvenator shows this immediately: addition of the rejuvenator until the original penetration is equal to the reference bitumen can decrease the stiffness, improve the fatigue and

decrease the resistance against permanent deformation. The EME research [12] shows that addition of RA increases the sensitivity to permanent deformation. For the stiffness and the fatigue only minor differences were found with or without RA. The properties of the binder and the way it is added are very important. In the NR2C-project at 40% RA a similar stiffness and marginal lower fatigue were measured compared to the reference mixture.
Also, when for instance the binder content is decreased for a better resistance to permanent deformation, it is possible that other properties are changed significant.
In an analysis of the FEC-StAB research [13] in the Netherlands it was found that that addition of RA will result in a decreasing healing-coefficient, a higher fatigue life and a lower stiffness compared to a base course StAC without RA.
It is remarkable that after compensation of the RA-bitumen with a rejuvenator or a softer bitumen, the stiffness is lower than was expected based on calculations for the blend. The cause can be found in different behaviour between the composed bitumen and a semi-composed bitumen by addition in an asphalt mixture plant: probably the binders do not homogenise completely or only a small part. This can leave a softer binder in a number of places in the mixture.
Shu [14] showed that the fatigue life improved when up to 30% of RA was used without compensation for the binder. The authors of the paper challenge the criteria used for determining fatigue life (50% reduction in stiffness). When a more recent method [15] with dissipated energy is used for the fatigue life, the use of RA leads to reduced performance. From the CROW-rapport on which results in [13] are based it becomes clear that at percentages of more than 50% RA, the fatigue behaviour of base course mixtures with binder contents between 4,5 and 5,0% is influenced negatively.
Finally it should be mentioned that prediction of mechanical properties of mixtures with RA based on bitumen properties is very uncertain. Separation and recovery techniques for regaining the bitumen to be tested from the RA can influence properties.

Healing

For the mechanism of healing addition of RA will mostly focus on the interaction between old and new bitumen. The mix of old and new bitumen is different from a new bitumen with the same penetration value. Both the Dutch and the Flemish approach with recycling are however based on the pen-rule because of its simplicity and practicality. Healing is in this case a very special one. At the moment there is no consensus on a standard test for healing, so the comparison of healing coefficients especially for mixtures with RA is not yet started. In the Netherlands one research is known in which RA was used to quantify healing [13,16]. At 60% RA the healing coefficient as determined with the four point-bending test under continuous and discontinuous loading, decreased from 4,8 to 1,4.

This result has indicated, as was feared by some, that the use of RA will result in loss of potential to heal. One view is that an addition of RA will increase the viscosity and prevent the closing of small cracks by flowing of molecules. The increased viscosity is thought to be caused by the shift of the chemical components in the bitumen. This will increase the concentration to large oxidized molecules and decrease the amount of ‘solving’ molecules. This is even valid for hard binders. A research at Artesis University [1] has shown that the concentration of carbonyl groups in hard bitumen is lower than in a RA-binder with the same penetration.
Cheng et al [17] showed that aging influences the surface-energy potential of the binder. The vanderwaals forces increase and the acid-base forces reduce resulting in an overall decrease of the the surface tension. According to [17] this can lead to decreased healing potential.

Antwerpen College and Delft University of Technology are developing a standard healing and fatigue test. The influence of the rheological behaviour and the chemical composition of the RA binder will be an important part of the final test.

4. Discussion

Recycling Reclaimed Asphalt is beneficiary. Addition of RA can lead to reduced economic and ecological cost. Some properties of the asphalt mixture will improve with addition of RA: examples are compaction, ITS-R and the stiffness. Other properties can decrease like resistance against permanent deformation. The quality of the RA-bitumen and the addition of RA in the mix are important factors. A softer bitumen will result in different properties compared to adding a rejuvenator. It is also possible to change the gradation and use different aggregate types. The influence on the properties has to be confirmed by testing.

The relative complex mixture design does not make it easy to use RA as a component in asphalt mixtures, nevertheless high percentages RA are used in the Netherlands and Flanders. The long term influence of high RA percentages is unsure, but in the Netherlands RA is used already on a large scale since 1980 and many road sections are probably recycled already twice. Unfortunately only global results like no dramatic increase of maintenance cost since 1990 are available. Some research on the use of RA show some mixed conclusions with regards long term effects on quality. The question is also how many times the bitumen is recyclable. Nobody knows.

An important observation in this paper was that the low temperature properties of recovered bitumen are overestimated. This is important for the evaluation of the behaviour of mixtures with RA at low temperatures.

The authors are of the opinion that replacement of the log-pen rule by G* measurements after short-term aging of the binder mix with a correction for the recovery process is a very good option.

Finally, further research and inventarisation of available test results on RA mixtures and the consequences of RA coming available in the future is a challenge for the coming years. In Flanders the increased amount of RA with PMB is important, while in the Netherlands the yearly increasing amount of RA from Porous Asphalt with very low penetration values is a real challenge.

5. Acknowledgements

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