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Recommendations and strategies for using reclaimed asphalt pavement in the Flemish Region based on a first life cycle assessment research

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Abstract. In Flanders, using Reclaimed Asphalt Pavement (RAP) is allowed in asphalt mixes for base layers. Primary economic and secondary laboratory-measured mechanical properties are given as justification for higher amounts in specific mixes. However, one should evaluate the performance of these mixes on long-term by environmental impact of the production until end-of-life. In this paper recommendations and strategies for using RA, based on current research, are discussed in a broader perspective such as using a carbon-footprint tool and warm-mix asphalt production in the Flemish Region. The paper aims to a wide discussion by reporting several outcomes of laboratory research, statistics and practical application in order to set a general strategy for the road engineering sector in the Flemish Region.

1. Introduction

Reclaimed Asphalt Pavement (RAP) is a typical by-product in the field of asphalt road rehabilitation these days but recycling of RAP is not a new technique since it was stimulated due to the oil embargo in 1973 and following sharp rise in all construction costs. In Europe, the use of RAP is common practice with some countries having more than 30 years of experience, such in the Netherlands [1], Flanders (Belgium) [2], Germany and Denmark [3]. Nowadays, RAP is considered as the most recyclable material in the construction industry and exceed typical recycling volumes for glass and paper [4]. According to the EU Waste Framework Directive 2008/98/EC, a recycling target of 70% for non-hazardous construction and demolition waste (including asphalt waste) should be achieved by 2020 [5]. Roughly 50 million tons of RAP are produced in Europe each year with over 70% of it being reused for pavement surfaces [6]. However, the asphalt recovery industry in some countries faces the problem of excessive material storage due to the limited quantities of RAP that can be reused in new mixes [7]. Several construction materials are composed by RAP, of which the most used are: asphalt mixes, cement-treated base and loose base materials. Most commonly, RAP is recycled in new asphalt mixes, since RAP is composed by asphalt components, but except it contains aged binder. The recycled hot asphalt mixes are made by several methods such as cold addition, pre-heated addition by a parallel drum and/or using rejuvenators. Reuse of this material is described in the EN 13108-8 standard [8], including material classification and testing.

2. Using RAP in Belgium

In Flanders, the Flemish waste policy is determined in the Flemish Waste Decree and its implementation order, the Order of the Flemish Government for the Establishment of the Flemish Regulations relating to Waste Prevention and Management (VLAREA) [9]. RAP is recognized as a secondary material since late eighties and currently, RA is accepted as a full material within the closed-cycle strategy as part of a circular economy.

In Belgium, exact data of the use of RAP are not available, however, for contractual reasons, the impartial certifying body COPRO monitors the quality of materials and the use of it for the production of asphalt mixes and bound base materials. According to the annual report of the European Association of Asphalt Manufacturers [10], it is estimated that 72% of an 1.5 million ton production of RAP are recycled annually in Belgium in hot mixes. Data from COPRO (year 2016) show that 0.95 million ton is recycled in asphalt, 0.64 million ton is used in foundations (base material loose and cement-treated).

In Belgium different rules for the addition of RAP are defined in the regional regulations (Flanders, Walloon and Brussels-Capital Region) and different works (public, private works or works with a certified mix). Depending on the material, regulations are described, mostly referring to European Standards, in regional technical standards. There is no official database available for RAP characterization in Flanders. Partly information can be obtained from the Flemish Road Agency (FRA) and COPRO. Currently, two new approaches for increasing the use of RAP are being developed: a sustainable selection model for the application of reclaimed asphalt granulate in road design (SSMARAGD) [11] and an IT-architecture for archiving the production and paving process of asphalt in order to provide data for later reclaiming activities [12].

3. Use of RAP in concrete

The use of RAP in concrete mixes for roads can be accepted as a new, even superior application than loose material for base construction. A number of researches have investigated the influence of RAP on the mechanical properties of concrete. Most of these studies have shown that RAP has a negative influence on the properties of the hardened concrete [13-15]. Nevertheless, using RAP in concrete could be useful to appoint non-useful RAP for asphalt, e.g. third generation RAP, lean RAP, etc. in a durable justified situation. Two studies elaborated in EMIB research group at University of Antwerp could be mentioned for that reason:

- In a first study [16] 4 concrete mixes were designed for cycle paths (compressive strength of 42.5 MPa) and tested, containing a percentage of 0; 25; 35 and 50 of RAP 0/20: slump test; modulus of elasticity; compressive strength test; density and air content were performed. The concrete mixes were designed with equal grading, cement and water content. In this phase, no optimization was done. An overall conclusion is that the properties are decreasing when adding RAP into a concrete mix. The compressive strength decreases from 26% up to 42%. It is estimated that 25% of the aggregates could be replaced by RAP to start optimizing concrete mixes.
- In a second study [17] the use of RAP in Portland cement concrete for roads (maximal 4 million ESA) was researched as alternative for virgin aggregates. The influence of RAP 0/20 on the mechanical properties of fresh and hardened concrete was evaluated. In order to determine this influence, an extensive laboratory study was performed on two types of mixes. The first type of mixes contained 25 or 35 percent RAP and the W/C - ratio was decreased to 0.45 and 0.42, while the reference mix had a W/C - ratio of 0.47. The second part of the experimental program focused on the influence of different RAP sizes used: the influence of a *fine and a coarse* RAP was evaluated. In these mixes 25 percent of the virgin aggregates were replaced by RAP. Only the mix proportion of the *fine* and *coarse* RAP varied. The RAP passing the 4 mm sieve was used as a replacement for the fine aggregates. The RAP retained on the 4 mm sieve was used to replace the coarse aggregates. Based on the test results and

discussion, the following conclusions can be drawn as follows: i) when RAP is added to the mixes the workability of the fresh concrete decreases due to the high absorption and internal friction of the RAP; also it is noticed that the *fine* RAP has a greater effect on the workability than the *coarse* RAP; ii) the RAP mixes show a systematic reduction in compressive strength with respect to the control mix; this is probably due to the reduced adhesion between the RAP in the mortar. Reducing the W/ C - ratio is an effective way the increase the compressive strength of the RAP containing mixes. Finally, it is observed that concrete mix holding only *fine* RAP, shows the least reduction in strength, iii) concrete made with RAP displays a lower dynamic modulus of elasticity and freeze - thaw resistance than the control mix, which can be improved by lowering the W/C – ratio, iv) RAP still absorbs water which must be taken into account for the calculation of the W/C ratio.

4. Use of RAP in asphalt mixes

4.1. Directives and technical guidelines

Strict guidelines on the nature of the reclaimed material (size distribution, bitumen content, filler content, bitumen viscosity or hardness, etc.) are enforced in the asphalt industry to guarantee good quality end materials. Homogeneity in terms of size, mineral type, binder type etc. is the most crucial quality criteria of RAP. In the ideal case, RAP is coming from only one source and one layer. Often this is not possible and RAP is mixed together from different pavement and locations. EN13108-8 standard leaves open to the countries to define a maximum particle size for RAP [18].

Issues related to the use of reclaimed binders are: variability of binder in RAP can generally be addressed by homogenizing the RAP stockpiles, hardness and level of recovered binder activation, compensation for the ageing process in the design of the added virgin binder, recyclability of any polymer modifiers, recyclability of asphalt with legacy materials, such as asphalt with coal tar or asbestos [10].

In Flanders, the use of RAP is described in the Flemish Standard version 3.1, TRA64 and TRA13 of COPRO, related to EN13108-8. Base course mix may contain unlimited content of homogenous RAP, when preheated at least at temperature of 110°C, but it is limited to 20% for EME-mixes and for mixes with cold-added RAP. All mixes must fulfil equal performance independent the RAP-content. Currently, mixes for surface layers may not contain RAP. Since it is allowed to use high RAP-content, a qualitative handling of the RAP is set.

4.2 Inventory of RAP and RAP-containing mixes in Belgium

In Belgium a slow increasing trend of using RAP is observed (see Figure 1). This means that the prohibition of using RAP in surface layers does not affect its use. A detailed analysis, based on data from COPRO, illustrates a consistency in grading and penetration (see Table 1), which is likely because the asphalt mix compositions in Flanders have hardly changed during the survey period.

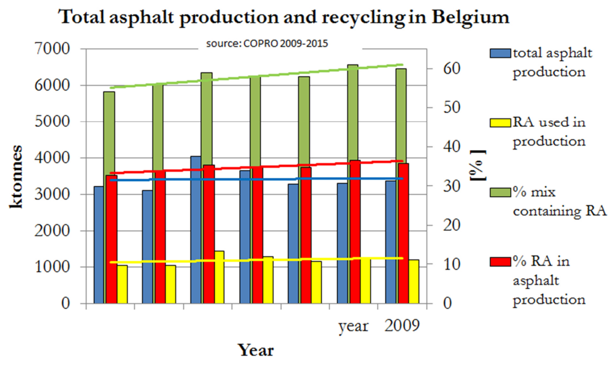

Figure 1. Data for asphalt recycling in Belgium [source: COPRO asbl].

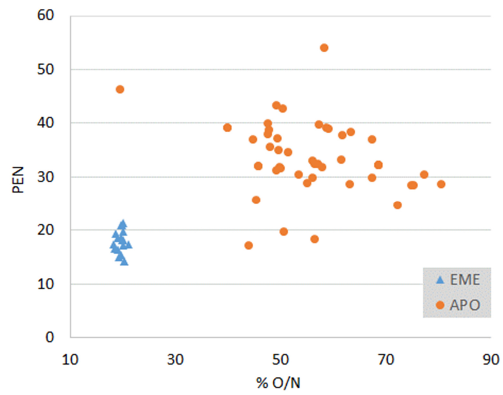

Figure 2. Penetration value of binder to ratio old/new binder in asphalt mixes [Data source: FRA 2015-2016].

Table 1. Binder penetration value of RAP stockpiles (n=number of selected stock piles [dmm]).

Year		n	Minimum	Maximum	Mean	Std. Deviation	Variance
2008	Penetration	95	11	31	20.7	4.5	19.9
2009	Penetration	105	11	38	20.6	4.6	21.2
2010	Penetration	96	13	46	20.6	4.8	23.3
2011	Penetration	104	11	36	19.5	4.6	20.8
2012	Penetration	117	12	37	19.8	4.0	15.9
2013	Penetration	98	14	41	20.0	4.7	21.9
2014	Penetration	111	13	45	20.0	5.7	32.9
2015	Penetration	101	13	30	18.8	2.8	7.7

Recycling techniques, which use old and milled asphalt to produce new asphalt, have been in use for over 30 years [4]. By the year 2010, it has been reported that hot asphalt mixes produced in Belgium, contained between 20% and 50% of RA [19]. Van den Kerkhof stated that at low recycling rates (≤ 20%), there are not much technical problems to use RAP. When higher levels of reuse are to be reached (50% or even more), a good product quality control and management is imperative to guarantee the conformity of production of the new bituminous layer. RAP is currently used in most APO (these are AC-mixtures for base layers) and EME mixes. The RAP/new-binder ratio for EME-mix is limited to 20%; for APO no limit is set. Practical reasons to limit can be found in the technical restrictions on the asphalt plant where a minimal quantity is necessary in the parallel drum to provide overheating. In Figure 2, a summary is given for the binder properties of EME and APO-mixes (registered by Flemish Road Agency 2015-2016). It is clear that APO-mixes contain even more than 50% of RAP-binder.

4.3 Mechanical properties of RAP-containing mixes in Belgium

In [20] and [21] a survey was done on the performances of asphalt mixes containing RAP. In these studies data from 65 technical justification notes (TJN) of asphalt mixes for base layers were analyzed. The RAP-binder content ranged from 0 to 76%. The mechanical properties rutting, fatigue and stiffness were compared. The study concluded that, using Spearman's rho correlation test, a statistically significant, but weak correlation was found for % old/new binder, rutting and for stiffness: the resistance to rutting and the stiffness of the mix increase if % old/new binder was higher.

Considering that all mixes fulfilled the requirements of the European standards, the mix was optimized whether RAP was used or not, such as using a softer binder to fulfill binder classes. When the dichotomous analysis was performed (0% RAP and >%RAP), it was observed that mixes containing RAP showed higher resistance to rutting and fatigue. No strong or robust correlation could be found between these mechanical parameters and %RAP, however the study revealed no adverse influence when using RAP in hot asphalt mixes. Other studies mentioned both positive as negative effects. It is recommended to analyze all these studies into one statistical study in order to find relevant parameters to adjust the mix design, if appropriated.

Since the use of RAP in surface layers is prohibited by SB250 v2.2 and later versions, questions arise whether the use of RAP in only base layers is too restricted; since there is still more RAP on the market. In order to start a research program, two typical mixes for surface layers were tested using RAP [22]. A dense asphalt AC-10, containing 5.6% binder (penetration 53 dmm) is used as reference. Mixes were produced containing 0% and 40% RAP. A softer binder (penetration 76 dmm) was used in order to compensate hard binder of the RAP. For this type of mix only %voids, wheel rutting and resistance to water sensitivity was tested. Compared to the reference mix, using 40% RAP was beneficial to rutting resistance and ITSR. SMA mix was also tested, using 20% and 30% RAP illustrating that RAP has a positive influence on the results for stiffness, rutting, ravelling and water sensitivity. Based on the research results, it is recommended to re-evaluate the current exclusion of the use of RAP in surface layer mixes and to initiate new test methods in order to evaluate mix long term performances, e.g. ravelling tests on aged specimens. Moreover, the prohibition for using RAP in surface mixes was set allowing up to 50% RAP, which is too high for these mixes under high environmental influence.

Some remarks must be pointed when RAP is used in mixes for surface layers. In Europe, the standard EN 13108-8:2005 for reclaimed asphalt establishes that if RAP content is higher than 10% for surface layers and 20% for base layers, a logarithmic blending law for penetration and a linear blending law for softening point should be applied to select the proper virgin binder to use. The Flemish approach with recycling RAP is based on the pen-rule in order to assign the new binder type, because of its simplicity and practicality [1]. A second issue is the use of polymer modified bitumen in mixes. The blending of old and new modified binder is very complex, maybe even case-dependant. There is a lack of guidance in this technology. Developing a proper binder blend's design between RAP binders and virgin materials is the first step for designing mixes with higher content. Currently, different approaches are being followed to carry out this task in different countries. In the U.S., for high RA contents (>20%), NCHRP Report 452 [23] described a particular procedure to obtain blending charts assessing high, intermediate and low critical temperatures of the blend of RAP and virgin binder [24]. Zhou et al. [25] developed a balanced RAP mix design for high RA content mixes for surface layers based on changing the binder content of the mix to optimize the maximum density, with 35% RAP content mixes designed with their methodology in different locations. The overall conclusion from the study was that high RAP mixes can have better or similar performance to virgin mixes, but they must be well designed following appropriate mix design methods. The use of RAP in surface layers might influence the RAP-handling into extra quality checks, e.g. types of aggregates and binder performance at a lower temperature.

The healing mechanism is one of the most important factors with significant impact on the performance of asphalt pavements. Investigators have expressed their belief that the healing mechanism not only can provoke total or partial restoration of the damage but can also extend the pavement service life [2, 26]. Currently there is no established test or procedure in order to study this phenomenon. In order to investigate this mechanism, researchers focused on the factors that mainly effect healing. Chemical and mechanical characteristics could provide an insight on the healing phenomenon and the properties that mostly trigger it [27]. Although, healing is a mechanism that can mainly effect positively the mixes service life, many researchers expressed their doubt about the effect of RAP on this phenomenon. A research conducted by Huurman [28] indicated that the shift factor of 4, established in the Netherlands as healing factor for bituminous mixes, can be reduced to 1.4 when

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60% of RAP is initiated. Clearly this addition of RAP can limit the healing mechanism, in an unknown extend until now.

Since healing tests are long-lasting and still under discussion, a new method to evaluate the healing property of an asphalt mix is necessary. A method performed with a Dynamic Shear Rheometer allows to compare mechanical properties for different types of mortar on cylindrical mortar samples, as first described for fatigue tests in [28] and further explored for healing tests by means of a procedure using continuous (10Hz, 15°C) and discontinuous (3s loading, 9s rest; stress-controlled) tests in [2]. The research showed that the healing property of 100% RAP mortar decreased significantly, compared to laboratory-aged mortar and virgin mortar. Since the healing factor is used as a constant for Flemish road design (factor 7.1) for each asphalt mix, an overestimation of the factor can result in faster deterioration of the road construction. It is recommended to quantify the healing factor for asphalt mixes when RAP is used, in order to optimize the mixes is such a way that the fatigue*healing is at least equal than for mixes without RAP.

5. Life cycle assessment of asphalt pavements

In Belgium, some steps were taken into the direction of a carbon-footprint tender including a carbon calculation tool [29], although it was found that there were many significant differences occurred comparing this tool and a detailed LCA study using Simapro software [20] such as different emission factors and the major contributor to the environmental impact is fossil depletion from raw material bitumen and transport. Important conclusions from the recent LCA study [21] are: i) LCA is very case-dependant and holds still a lot of uncertainties, ii) in the specific case, a standard rehabilitation of a dual carriage road by toplayer and baselayer using 0% and 44% of RAP-binder, the two impact categories related to climate change (human health and ecosystems) are together, with 47%, the main contributors to the single score impact. Transport by lorry (47%, including upstream processes) and heat generation (18%) mainly cause the climate change impact, iii) using RAP leads to environmental benefits mainly coming from the avoided amount of crushed gravel, limestone powder and the total amount of bitumen. Impact categories climate change human health (29%), particulate matter formation (19%) and fossil depletion (19%) are the main contributors to this environmental benefit, iv) the benefits only stand when the same service life of the asphalt mixes with and without RAP is obtained.

In general, much more analysis should be done concerning the transport aspect of asphalt mixes, the environmental impact of the use of additives - even rejuvenators - in combination with the service life for asphalt mixes with RA. This service life must be seen as larger than only the fatigue life, e.g. also the resistance to rutting and healing mechanisms. When the service life is theoretically decreased by 20% (e.g. simplified as e6 80 µS instead of 100µS), all environmental benefit is gone when the pavement thickness is increased to compensate this inferior property. This means that using RAP at a high content is only beneficial when also the performance of the mixes containing RA is equal, since transport of material is dominant. The above discussed and accepted means that mixes containing RAP can be designed and produced with equal performance. It is also concluded that the distance between asphalt plant and the work site is an important factor considering the environmental impact of work. Another way to work with reduced environmental impact of asphalt mixes, is the use of reduced production and compaction temperatures. An LCA comparative calculation of a standard mix, a mix produced at decreased temperature and a mix containing 50% RA tend to a conclusion that using RAP is more effective than decreasing the temperature by 30°C. During the project Re-Road [30] the life cycle benefits were investigated from recycling versus using warm mix asphalt (WMA), and demonstrated that even at low recycling rate of 15%, the recycling benefits outweigh those achieved by reducing temperature from 165 to 130 °C. Discussion about the performance and technical production challenges of these WMA mixes in Flanders, leads currently to an on-hold situation.

6. Strategies by conclusions for optimizing the use of RAP in Flanders

In Flanders, high recycling rates of RAP in asphalt mixes for baselayer are used. However, data showed that not all RAP available on the market is used in these mixes, which is currently accepted as one of the best recycling application in Flanders. In order to optimize the use of RAP in a sustainable way, the next steps should be taken into account:

i) The LCA-method is a new tool giving more insight in the environmental effect of production methods, transport and the use of by-products or enhancers (rejuvenators, waxes). Still there is a lack of data and consensus in order to calculate absolute impact values. Comparative studies can be done with this tool and showed that the use of RAP is beneficial to the use of warm asphalt mixes without RAP.

ii) The asphalt mixes currently used, all meet the mechanical requirements, tested in laboratory. In order to evaluate the effect of RAP in situ, the initiation of an inventory of pavements, of which the mix composition and the traffic volume is monitored, is strongly recommended. An important parameter is absent: the healing factor is not well-studied and is related to the use of RAP. It is recommended to test a selection of the mixes also on their healing capacity combined with the fatigue performance: an LCA-study stated that all environmental benefits are counteracted when RAP decreases the service life performance of the mix. Future comparative studies should only take into account optimized mixes, assessing the environmental impact of that optimization.

iii) A statistical analysis taking into account all mechanical performance and mix compositions would provide insight in the effect of RAP on the mechanical durability performance.

iv) The step to use RAP in mixes for surface layer is self-evident for limited recycling rates e.g. 25% taking into account additional quality checks of the RAP used and mix performance.

v) The blending process of mixes using polymer modified binder, rejuvenators, multiple recycled mixes or at higher recycling rates still needs more research. The current pen-rule does not cover the required performance expected: when new binders are used in asphalt mixes, these binders are extensively tested for a wide range of temperatures and ageing conditions; when e.g. 70% of the binder consists of RAP-binder, only the penetration value must meet the binder class. Durability performance on long term or other conditions are neglected.

vi) The use of RAP in concrete for road constructions, is at this moment not beneficial taking into account the mechanical performance. Only low contents can be used. An LCA study can give the environmental information to decide its applicability.

vii) The LCA-study demonstrated that transport of materials is one of the most dominant factors in the asphalt process. An effective RAP management tool for appointing the best recycling process for a geographical area, on the plant or even recycling in situ could be in this case a promising technology. It is recommended for larger projects to incorporate an environmental tool for comparative studies of the available technologies.

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