Recycling reclaimed asphalt in Flanders: state of the art 2014

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ABSTRACT

This contribution illustrates the state of the art of the use of reclaimed asphalt pavement (RAP) in bituminous mixtures for roads in Flanders. A first part will give a summary of the supply of reclaimed asphalt and its use for the last decade in Flanders. Different mixtures with the use of RAP are compared by means of stiffness and fatigue properties.
In Flanders, the regulation and the composition of asphalt is different for non-public and public works. For the latter, the Flemish Regulation must be followed and till 2011 recycling was allowed both for mixtures for base and surface layers, up to 50% binder substitution. However, after 2011 recycling became prohibited for top layers. Since 2013, the Flemish Agency for Road and Traffic and the University of Antwerp started an experimental program to evaluate the limited use of reclaimed asphalt in mixtures for surface layers, e.g. AC-10 and SMA. A LCA study showed that the use of RAP is beneficial compared to the use of warm mix asphalt.
Further, in this paper, the results of this experimental program for AC-10 and SMA with RAP are discussed. The study recommended allowing the use of RAP up to 50% for AC-10. In a second project, the performance characteristics of SMA mixtures (SMA-C1 with 70/100 and SMA-C2 with 45/80-50) with reuse of reclaimed asphalt pavement are explored. The experimental study of the performance characteristics consist of % Voids, resistance to water sensitivity, rutting, stiffness modulus and ravelling (Darmstadt scuffing device prTS12697-50). The study showed that the addition of RAP has no negative effect on the performance of the mixtures.
The contribution concludes with a recommendation to re-evaluate the prohibition of RAP in surface layer mixtures.

Keywords: Environment, Life cycle assessment, Mechanical Properties, Reclaimed asphalt pavement (RAP) Recycling, Stone Mastic Asphalt

1. INTRODUCTION

Every year numerous roads are rehabilitated or renewed. In Belgium, the total quantity of reclaimed asphalt pavement (RAP; in Belgium also the acronym RA is used), available and allowed to be reused in the production of hot mixed asphalt, is estimated to be 1.5 Mton per year. The use of RAP can have a large influence on future road constructions and the environment. Both mechanical as ecological impact are important to cover when a material is recycled. Also the economic value of RAP and the cost of primary materials will have influence on its use. Nevertheless, the asphalt sector supports the idea to increase the recycling rate of RAP without decreasing the (mechanical) durability of the asphalt mixture and some research is done in order to assess the environmental impact of the use of RAP e.g., by Life Cycle Assessment studies.

In this contribution a state-of-the-art is given for the use of RAP in Flanders, the Northern part of Belgium. First the legislation is explained and fact and figures are given. RAP is often used in base layer mixtures; in surface layers RAP is nowadays prohibited, though, industry, academic research institutes and road agencies point to reintroduce the use of RAP. In this view, in a second part, two preliminary researches are summarized in this contribution.

2. THE USE OF RAP IN FLANDERS: STATE OF THE ART

2.1 Flemish Regulation for the use of Reclaimed Asphalt in Public Works

The use of RAP in mixtures for public works, is described in the Flemish Standard which is revised every four years.

In Flanders, RAP is used as loose aggregate (unbound base material), as cement-treated base material and in asphalt mixtures. For road base mixtures (cold application treated with cement or loose) the use of RAP is unlimited. In this contribution, only the use of RAP in asphalt mixtures is discussed.

Before 2011, in asphalt mixtures, the use of RAP in hot mixtures was accepted to a maximum of 50% addition of RAP for both base and surface layer mixtures, depending on the method of preheating (parallel drum or cold addition) and the homogeneity of the RAP. The quality requirements of RAP are defined in additional documents related to EN13108-8 and Flemish regulation.

Since 2011, according to SB250 v2.2 [1], the use of RAP in asphalt mixtures for surface layers was prohibited in Flanders and only allowed in base courses, restricted to specific amounts and mixtures as prescribed in the legislative documents for public roads. For base course mixtures, there was a distinction between base course layers according to the empirical method and the fundamental method (EN13108-1). According to the empirical method, the allowed amount of RAP in the mixture is expressed as binder quantity and restricted by the way of addition in the mix. If the RAP is added without heating the RAP (cold application) the amount of binder from the RAP is restricted to 20%. If the RAP is preheated by a parallel drum (hot application) the quantity of binder from RAP is restricted to maximum 50% for homogenous RAP and 20% for inhomogeneous RAP or a combination of both.

Overall, the approach of SB250 provides no difference in mixture requirements between mixtures with or without RAP, where allowed. The empirical method is limited to composition restrictions and typical mixture properties such as compactibility, wheel rutting and water sensitivity. As opposed to the empirical method, the fundamental method includes fewer requirements on materials and mixture composition, but defines two more requirements on the performance of the asphalt mixture: stiffness and fatigue characteristics.

In 2015, SB250 v2.2 was revised to a newer version SB250 v3.1 [2], the current version. The use of RAP in asphalt mixtures for surface layers is still not allowed in Flanders. For base courses, only mixtures designed by the fundamental method are allowed and only homogenous RAP can be used. If RAP is added with preheating (minimum 110°C), the amount of RAP-binder in the new mixture is unlimited. The amount of RAP-binder is limited to 20% for EME-mixtures and for mixtures with cold-added RAP.

We can conclude that the current version of SB250 v3.1 allows the use of more, even unlimited, homogenous RAP for base courses, depending on the way of preheating and on the type of mixture. However, the addition of RAP to the mixture may not result to inferior mixtures.

2.2 Facts and Figures

For the Belgian asphalt sector, two organisations keep a record of production data: EAPA (the European Asphalt Pavement Association) and COPRO (abbreviation of 'Control of Products' representing the Belgian Impartial Certification Body in the Construction Sector). Data from EAPA are an estimation of the national industry sector, made by the Belgian association of asphalt producers. These data do not allow to make a distinction between the production in Flanders (20 asphalt plants) and Walloon (19 asphalt plants). COPRO publishes the results of measurements on certified asphalt mixtures and certified asphalt plants. 17 Flemish, 4 Walloon and 1 Dutch asphalt production plant are COPRO certified, meaning 3 Flemish and 15 Walloon asphalt plants are not certified and thus excluded from this COPRO data collection. The recent annual report of EAPA (2013) is compared to the corresponding data from COPRO and summarized in Table 1. The figures from EAPA and COPRO vary significantly, due to the different scopes of the reports. Nevertheless, the figures give an indicate of the order of magnitude of production figures. When asphalt mixtures are used for public works, RAP must also be certified, e.g. by COPRO. In this way, data obtained from COPRO are more appropriate to use for further analysis.

Table 1: figures for Belgian asphalt sector in 2013 [3], [4]

	EAPA	COPRO
Asphalt production (million tons)	5.3	3.3
Available amount of RAP (million tons)	1.5	0.85 – 2.0
Mixtures containing RAP (%)	51	58
Average RAP content (%)	33	45

Analysis of COPRO data since 2010 [3], [5], [6] reveals that the highest annual asphalt production was 4.04 million tons in 2011. This is an increase of 30% compared to the annual asphalt production in 2010 (3.11 million tons). From 2011, there is a decrease until 3.29 million tons in 2013 and a stagnation in 2014 with 3.31 million tons. The peak in the annual asphalt production in 2011 is due to the Belgian effort to counteract the considerable arrears in maintenance and repair of road pavements.
Asphalt concrete is the mixture that is most produced in Belgium with 82% of the total asphalt production. In second place comes the SMA mixtures with 15% in 2013 and 2014. The Flemish Road Standard SB250 prescribes the requirements (from material characteristics to performance tests on the pavement) for all public road works in Flanders. Before 2013, the SB250 limited the amount of RAP to 50% for base course mixtures. Since 2013, performance requirements (fundamental method NBN-EN 13108-1) were integrated in SB250 as an alternative for the empirical method for base courses.
The EAPA and COPRO data (see Table 1) show that in 2013, more than half of all produced asphalt mixtures contained RAP. Approximately 2 million tons RAP was available for the market, only 0.85 million tons was used in new asphalt mixtures.
In 2014, the rate of asphalt mixtures containing RAP increased to 61% with a total use of 865.810 tons of RAP. The average rate of RAP in mixtures with recycling was 43% in 2014. Nevertheless, 26% of the 2.01 million tons of asphalt mixtures which are produced with recycling are non-specified mixtures which are used for private works, other 74% are used in registered mixtures used for public works.
The use of RAP in asphalt mixtures became common practice; even recycling rates up to 100% would be possible in the future by fractionating the RAP and adding a rejuvenator [7].

2.3 Justification of the use of RAP in mixtures for base course layers

It is seen from §2.2 that the use of RAP in new hot and warm asphalt mixtures became common practice in Flanders, although the impact of RAP on the mechanical performances of asphalt mixtures in the long run are, still, unknown. During the past decade, in Flanders, several studies were done to evaluate the mechanical durability of RAP-containing mixtures, e.g. the compatibility of the RAP-binder mixed with new binder (low and high temperature performance) and the effect of RAP on the water sensitivity performance [8]; the effect of RAP-binder on fatigue and healing properties of bituminous mortar samples [9], the use of RAP mixed with bituminous roofing waste in mixtures for base layers with high modulus [10]. Generally accepted, one can design asphalt mixtures for base layers using RAP without decreasing the mechanical performances. However, one should take into account that a simple 1:1 replacement for binder and aggregates–which was often the case – can lead to inferior mixtures, especially at high recycling rate. For example, in [9] it was illustrated that a 100% bituminous RAP mortar showed decreased healing properties. Unfortunately, *in situ* measurements of mechanical properties of mixtures containing RAP over a long period (e.g. 20 years) are lacking.
Since the use of RAP can affect the final mixture performance, in particular due to its variable composition, it is imposed by recent SB250 versions that the mixtures are tested with the specific used RAP, strictly defined by homogeneity, aggregate size and penetration value of the binder. The requirements of the final mixtures are equal, whether using RAP or not.
Asphalt mixtures for base courses designed with the fundamental method, are subjected to a series of lab tests (i.e., air voids content and compactibility, water sensitivity, rutting resistance, stiffness and fatigue) prior to acceptance for use on public roads in Flanders, according to SB250 v2.2 and following versions.
Since 2011, data is collected of these tests and initially used for the analysis of the impact of RAP on rut resistance, stiffness and fatigue. In order to gain insight in the effect of using RAP, the mechanical properties of 65 different asphalt mixtures were analysed with RAP content ranging from 0 up to 63% and with a mixture composition, which is already optimized in order to counteract effects of the RAP. Unlike numerous case specific laboratory researches, the current research investigates the performances of asphalt mixtures in compliance with the identical composition on the road.
The resistance to rutting was analysed based on the average of two measures of the rutting depth after 30.000 cycles. The stiffness E* (MPa) was measured according to EN12697-26 on trapezoidal cores with the two point bending test at 15°C and 10 Hz. The test was carried out in 'constant displacement mode' and at an imposed strain of 50µm/m. The

resistance to fatigue (ε6) was measured according to EN 12697-26 with frequency at 15°C and 30 Hz. The value ε6 is the maximal strain that should be imposed so that the material is able to resist one million of load repetitions.
The available data from laboratory tests were subjected to a statistical analysis in order to search for a relation between the percentage of RAP in the mix or the percentage of old bitumen versus new bitumen and the three mechanical performances.

Following conclusions are drawn:

- Adding RAP to an asphalt mixture has a positive effect on the resistance to rutting.
- No statistically valid results were found for the impact of RAP on the stiffness of asphalt mixtures.
- There is a statistically significant proof that the fatigue life of asphalt mixtures with 20% RAP is higher compared to asphalt mixtures with higher rates of RAP. Adding 20% RAP could have a beneficial effect on the fatigue of the asphalt.

Analysis of the test results does not reveal any adverse influence on the mechanical properties from RAP. Some advantages of using RAP in asphalt mixtures were found and hence adding RAP may even have a positive influence on the service life of a road pavement. Nevertheless, the influence of RAP on the service life of bituminous base courses should be investigated in practice. Further, mixtures with RAP are designed in order to meet at least equal mechanical properties as mixtures without RAP.
The findings as described above justify the assumption of equal service life for bituminous base courses without RAP and with RAP. A theoretical cradle to gate life cycle assessment (LCA) case study [11] compares dense mixtures for base courses: i) a reference hot mix (REF), ii) a warm mix asphalt (bitumen foaming technique) (WMA) and iii) a hot mix with 50% recycling (RAP). The mechanical performances were assumed to be the same for the three mixtures. Figure 1 illustrates the single score environmental impact per damage category for the three different mixtures. The production of the hot mix holds the largest environmental impact. The environmental single score impact of the warm mix asphalt production and the production of the hot mix with RAP are decreased with respectively 2% and 41% compared with the reference.
Although these results come from a limited theoretical LCA case study, it is concluded that the use of RAP in new asphalt mixtures is beneficial for the environmental impact. It is recommended for future LCA-calculations to collect data from field experiences, specifically the service life of asphalt pavements and its composition.

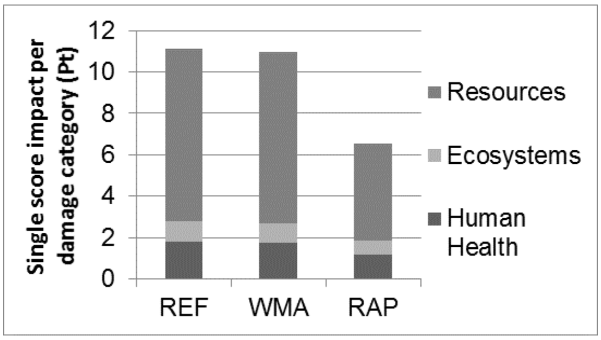

Figure 1: Comparison of environmental single score impact for three asphalt mixtures [11]

3. PRELIMINARY STUDY INTO THE USE OF RAP IN STONEMASTIC ASPHALT

The most commonly used asphalt mixture for surface layers of primary and secondary road network in Flanders is Stonemastic Asphalt (SMA). Currently, questions arise to use RAP again, after years of exclusion in surface layers. Specific mixtures can be defined in future standards as “APT” which stands for (translated from Dutch) Asphalt Mixtures with Performance characteristics for surface layers. This type of mixture definition could allow the use of RAP, if its performance is verified.
In this research part, the performance characteristics of SMA mixtures with RAP is explored. This preliminary study is a subsequent research after finalizing and reporting the ReRoad-project [12,13], adapted to Flemish specifications.

3.1 Mixture Design

Two reference mixtures were designed: SMA 10 70/100 (MIX 1) and SMA 10 Pmb 45/80-50 (MIX 2). In these two mixtures 20% RAP (MIX 1.20 and MIX 2.20) and 30% RAP (MIX 1.30 and MIX 2.30) is used. For the mixtures containing RAP, in each case new aggregates were added in order to meet the grading of the reference mixture. The grading of all mixtures is illustrated in Table 2. The objective of this study was to determine the limit for the rate of RAP without adjusting the binder type; in this way ‘harder’ binders were expected in the mixture with RA. In a second stage, not reported in this contribution, other virgin binder types will be selected in order to improve mixture performances.

Table 2: Grading of SMA mixtures

Mixtures	14	10	8	6.3	4	2	1	0.5	0.25	0.063
MIX 1	100	91.1	58.4	37.2	29.0	27.2	19.6	14.8	11.9	8.2
MIX 1.20	100	91.1	58.4	36.5	29.5	26.0	18.9	14.6	11.4	7.9
MIX 1.30	100	91.3	59.7	37.8	30.1	25.3	18.8	14.5	11.4	8.2
MIX 2	100	93	67.5	48.9	30.7	27.3	19.6	14.8	11.8	7.9
MIX 2.20	100	93	67.5	48.9	31.3	26.1	18.9	14.8	11.4	7.9
MIX 2.30	100	93.1	67.8	48.3	31.9	25.9	19.0	14.7	11.5	8.0

The RAP which was used, was a homogenous RAP with AC-10 origin (binder content 5.79%; with a non-modified binder penetration 20dmm and R&B 65.5°C). The binder properties of the SMA mixtures are given in Table 3.

Table 3: Binder properties of the SMA-mixtures

Mixtures	Penetration [dmm]	Softening Point [°C]
MIX 1	74	47
MIX 1.20	38	56.8
MIX 1.30	35	60.4
MIX 2	57	55.3
MIX 2.20	33	65
MIX 2.30	24	71.8

The performance characteristics of the different mixtures are evaluated by:

- The gyratory compactor test for the determination of the % voids in accordance with EN 12697-8 (Compactibility 100% - 120 gyrations);
- The indirect tensile test with and without conditioning in water for the determination of the water sensitivity according to EN 12697-12 (low compaction 25 gyrations);
- The two-point bending test stiffness according to EN 12697-26 (15°C, 10 Hz);
- The wheel tracking test for the determination of the resistance to permanent deformation according to EN 12697-22 (at 50°C, 1 Hz, 30000 cycles);
- The DSD (Darmstadt Scuffing Device) test for the raveling sensitivity.

3.2 Compactibility – Volume of Voids

In Table 4 the results for the volume of air voids (% voids) of the different compacted mixtures are listed, in accordance with EN 12697-8 (120 gyrations). According [1], the aimed % voids for SMA 10 is 5-11%.

Table 4: % Voids in mixtures

Mixture	Density (kg/m³)	n	% Voids mean	SD
MIX 1	2465	3	7.77	0.25
MIX 1.20	2466	3	9.88	0.54
MIX 1.30	2470	3	9.56	0.43
MIX 2	2447	3	8.78	0.14
MIX 2.20	2472	3	9.92	0.04
MIX 2.30	2463	3	10.7	0.69

For all mixtures, the % voids values are achieved within the specifications mentioned in [1]. It is noticed that when RAP is added, the values of the % voids increase significantly, which is probably caused by the harder binder mix, since no softer binder is used and the gradation is similar.

3.3 Water sensitivity

In Table 5, the results of the ITS and ITS-R are given. The samples for ITS are compacted by 25 gyrations, without a target value for voids. The samples of two series (dry and wet series) must be arranged in such a way that the mean density of both series is similar. In this way, the effect of voids is countered. There is no significant difference for ITS or ITS-R for the mixtures containing a standard binder. For the mixtures with polymer binder, the ITS-R value decreases when RAP is added to the mixture. According to SB250 v2.2 and v3.1, all the mixtures meet the condition of 80% ITS-R.

Table 5: Water sensitivity of the SMA Mixtures

Mixture	ITS_{wet} (N/mm^2) (SD)	ITS_{dry} (N/mm^2) (SD)	ITS-R (%)
MIX 1	0.903 (0.107)	1.032 (0.059)	87.6
MIX 1.20	0.927 (0.218)	1.114 (0.145)	83.2
MIX 1.30	0.967 (0.117)	1.062 (0.055)	91.1
MIX 2	1.175 (0.121)	1.326 (0.008)	88.6
MIX 2.20	1.068 (0.225)	1.321 (0.075)	80.9
MIX 2.30	0.958 (0.252)	1.177 (0.144)	81.4

3.4 Stiffness modulus

In Table 6, the results for stiffness modulus of the mixtures at 15°C and 10 Hz are given. The results illustrate that, for all mixtures, the stiffness increases when RAP is added. The mixtures containing polymer binder show slightly lower moduli than those with standard binder. All mixtures meet the requirement of the minimum value of 7000 MPa for top layer mixtures in [2].

Table 6: Stiffness modulus for SMA-mixtures

Mixture	N	Smix (MPa)	SD
MIX 1	5	8831.67	440.38
MIX 1.30	6	10730.33	381.14
MIX 2	5	8180.17	647.48
MIX 2.20	6	8920.5	491.44
MIX 2.30	6	9715.67	417.47

3.5 Wheel rutting

In Table 7, the results of the wheel tracking test are given.

Table 7: Rutting for SMA-mixtures

Mixture	Rutting Pi % @ 30000	SD
MIX 1	4.66	0.425
MIX 1.20	4.89	0.185
MIX 1.30	3.31	0.075
MIX 2	3.42	0.325
MIX 2.20	3.33	0.38
MIX 2.30	2.6	0.005

For both type mixtures, the addition of RAP shows a positive influence on rutting resistance. The mixtures containing polymer binder seems to hold a better resistance to rutting. All mixtures encounter the standard requirements for highest traffic class (max.5%).

3.6 Raveling: Darmstadt scuffing device

For SMA, a new type of test will be introduced in the next version of SB250: the resistance to raveling. Figure 2 represents the results of the DSD test, performed at the Belgian Road Research Centre (Figure 3).The standard settings that are used: sample temperature 40°C, 10 cycles with a vertical load of 1000N giving a wheel pressure of 300kPa. The lost material after 10 cycles is weighed (in g/m²). This test method, in its present conditions, is being evaluated by BRRC.

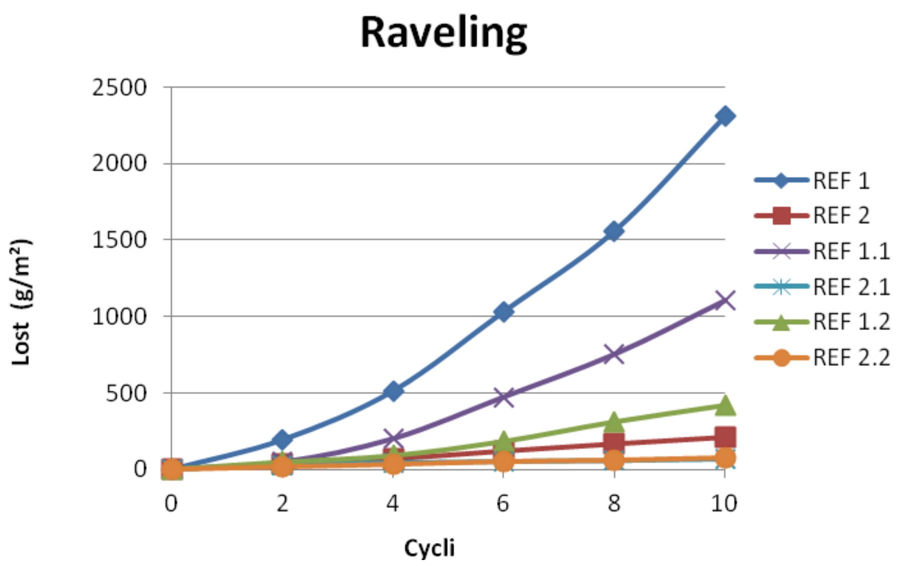

Figure 2: Result of raveling DSD test on 6 mixtures

Figure 3: Set-up of Darmstadt scuffing device

For both mixture types, the result of the addition of RAP is similar: the raveling sensitivity decreases or is similar when more RAP is added to the mixture. Still, there is a significant difference according to the binder type. The mixtures containing polymer binders are less sensitive to raveling. We can conclude that the addition of RAP and the use of polymer binder contain a positive influence on the resistance to raveling.

3.7 Conclusion

This preliminary study shows that the addition of RAP to SMA mixtures, without changing the virgin binder, has a positive influence on the performance characteristics for stiffness, rutting, raveling and water sensitivity.

4. PRELIMINARY STUDY INTO THE USE OF RAP IN DENSE ASPHALT CONCRETE

In this section, another preliminary research is reported concerning the performance of dense asphalt concrete surface courses using RAP. This type of mixture is used on secondary and local roads.
The reference mixture is a standard AC-10 with a penetration binder. The mixture design of four mixtures (0%, 20%, 40% and 50% RAP) was done with Pradowin software. The binder content was kept equal for all mixture to 5.60 mass % in the mixture. The average binder content in the RAP is 6.31 mass %. The specific details of all the mixtures are shown in Table 8.

Table 8: Specifications of the mixture design

Mixture	REF	M1-20 %	M2-40 %	M3-50 %
% RA-bitumen	0	20	40	50
% new bitumen	100	80	60	50
Type of new bitumen	50/70	70/100	70/100	70/100
PEN new bitumen (dmm)	53	76	76	76
PEN mixed bitumen (dmm)	-	62	50	45
Softening point (°C)	47.8	48.3	51.8	53.6
Bitumen (mass % in mixture)	5.60	5.60	5.60	5.60
Stones in the mixture (mass %)	54.36	54.17	54.41	54.25
Sand in the mixture (mass %)	33.43	33.78	33.65	33.54
Filler in the mixture (mass %)	6.61	6.45	6.35	6.62
Binder in the mixture (mass %)	5.60	5.6	5.60	5.60
Voids (%)	4.77	5.16	5.20	5.24

In order to specify the performance characteristics of the different mixtures, the following tests were executed:

- The gyratory compactor test for the determination of the % voids in accordance with EN 12697-8:2003 (60 gyrations);
- The indirect tensile test with and without conditioning in water for the determination of the water sensitivity according to EN 12697-12:2008 (25 gyrations);
- The wheel tracking test for the determination of the resistance to permanent deformation according to EN 12697-22:2003 + A1: 2007.

The results of these tests are given in Table 9. Based on the results of this study, the conclusion is that adding RAP, up to 50% RA-bitumen, do not lead to inferior mixture performance. The mixture containing 50% of RA-binder showed the best results.

Table 9: Summary of the test results of AC-10 mixtures

Property	REF	M1-20 %	M2-40 %	M3-50 %
Voids (n=3) (%)	7.11	7.44	8.31	6.89
ITS dry (N/mm²)	1.98	1.61	1.97	1.99
ITS wet (N/mm²)	1.12	0.72	1.15	1.38
ITS-R (%)	56.2	44.7	58.6	69.2
Wheel rutting (Pi%)	11.29	8.19	7.21	6.67

5. CONCLUSION

In Flanders, more than half of the manufactured asphalt mixtures contains RAP. The use of RAP in asphalt mixtures is assumed to be beneficial for the environment. Though, attention must be given to the performance of the final mixture: its performance may not decrease the environmental and mechanical durability.
The approach of SB250 v3.1 provides no difference in mixture requirements between mixtures with or without RAP. For mixtures for top layers, no RAP is allowed; RAP is allowed only in base layer mixtures. During manufacture, the quality of RAP (homogeneity, grading, binder) must be kept constant in time, and equal to the RAP used in the mixture design and experimental program.
In this study an analysis is reported of the mechanical properties of 65 different hot mix asphalt for base layers with RAP content ranging from 0 up to 63% and with a mixture composition which is already optimized in order to counteract possible negative effects of the RAP. Analysis of the test results does not reveal any adverse influence on the mechanical properties from RAP. Some advantages of using RAP in asphalt mixtures were found for resistance to rutting and fatigue; hence adding RAP may have a positive influence on the service life of a road pavement.
By means of a LCA study it is illustrated that the use of Reclaimed Asphalt Pavement is beneficial for the environment, even more than the use of warm mix asphalt.
In order to future use of RAP in surface layers, currently prohibited, two preliminary studies on a dense asphalt mixture and SMA were reported. These studies showed that the addition of RAP has no negative influence on the performance characteristics tested. This is manifested explicitly in the results for rutting and water sensitivity in both mixtures and also for raveling in SMA. Based on these results, it is recommended to re-evaluate the current exclusion of the use of RAP in surface layer mixtures.
Furthermore, since all design and testing are performed on unaged mixtures, and due to the lack of mechanical data from field experience, new test methods should be initiated in order to evaluate long term performances of the mixture, e.g. raveling tests on aged specimens. It is recommended for future LCA-calculations and road design, to collect data of the real service life of asphalt pavements, related to the composition of each layer and the amount of RAP used.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

[1] *Flemish road standard (Standaardbestek 250 voor de wegenbouw) version 2.2.*, Vlaamse overheid, Flemish Road Agency, Brussels 2011.

[2] *Flemish road standard (Standaardbestek 250 voor de wegenbouw) version 3.1.*, Vlaamse overheid, Flemish Road Agency, Brussels 2014.

[3] *Activity Report 2013* (Activiteitenverslag 2013), COPRO, Brussels 2014.

[4] *Asphalt in Figures 2013*, European Asphalt Pavement Association, Brussels 2014.

[5] *Activity Report 2012* (Activiteitenverslag 2012), COPRO, Brussels 2013.

[6] *Activity Report 2014* (Activiteitenverslag 2014), COPRO Brussels 2015.

[7] *Best available techniques for asphalt plants (Beste Beschikbare Technieken voor asfaltcentrales)*, D. Leyssens, B. Verstappen, and D. Huybrechts, BBT-kenniscentrum VITO, Mol 2013.

[8] *Study of the compatibility of binders using Reclaimed Asphalt Pavement, Final Report*, A. de Jonghe, W. Van den bergh, C. Vuye, G. Schoeters, J. Verheyen and F. Van Leugenhagen, Eindrapport (In Dutch), Hogeschool Antwerpen 2006.

[9] *The influence of ageing on the fatigue and healing proprties of bituminous mortars*, W. Van den bergh and M. van de Ven, Procedia : social and behavioral sciences - ISSN 1877-0428 - 53(2012), p. 256-265, 2012.

[10] *The use of bituminous roofing waste material for road construction : aged-bitumen bound base aB³*, (Nuttige aanwending van bitumineus dakdichtingsmateriaal in de wegconstructie), W. Van den bergh, C. Vuye, F. Swenters, XXII Belgian Road Congress, Luik 2013.

[11] *Cradle-to-Gate Life Cycle Assessment of Recycling and Impact of Reduced Production Temperature for the Asphalt sector in Belgium*, J. Anthonissen, W. Van den bergh and J. Braet, International Symposion on Pavement LCA 2014, no. 1, pp. 61–74, 2014.

[12] *Re-Road project*, End of Life Strategies of Asphalt Pavements, FP7-project 2008-2013, grant 218747, B. Kalman www.re-Road.fehrl.org

[13] *Fatigue and healing peformance of bituminous binders and mixtures for road pavements*, W. Van den bergh, C. McNally, A. De Keersmaecker and E. Fallon, IV Int. Conf. on Self-Healing materials ICSHM, Gent 2013.