LOWERING THE PRODUCTION TEMPERATURE OF ASPHALT WHILE INCORPORATING A HIGH PROPORTION OF RECYCLED MATERIAL

G. van Bochove, H. Bolk, K. Poncelet, M. Lecomte

Gerbert VAN BOCHOVE, Heijmans – Breijn, P.O. Box 2, 5240 BB Rosmalen, The Netherlands / gbochove@breijn.nl
Hans BOLK, Heijmans – Breijn, P.O. Box 2, 5240 BB Rosmalen, The Netherlands / hbolk@breijn.nl
Michaël LECOMTE, Société des Pétroles Shell, France / michael.lecomte@shell.com
Karel PONCELET, Belgian Shell, Belgium / karel.poncelet@shell.com

ABSTRACT

The environmental footprint of asphalt mixtures can be reduced by production at lower temperatures and by the increase of recycled asphalt percentage. However, a reduced asphalt mixture production temperatures may result in the old asphalt particles - containing hard and brittle bitumen - not melt and disintegrate completely leading to a non-homogeneous asphalt mixture and a shorter service life on the road.

By surveying the CO_2 footprint of asphalt production, it is shown that the CO_2 equivalent savings achieved by recycling old asphalt far outweigh those that may be achieved by reducing the production temperature. Therefore, aiming to reduce CO_2 emissions through reduced mix plant temperatures but reducing also the recycled asphalt content is counterproductive. Performance and footprint advantage are to be gained through increasing the amount of recycled material and appropriately pre-treating it.

A new process to pre-treat the old asphalt granulates, based on the two-phase Shell WAM Foam process allows to maximize the fraction of recycled material and reduce the environmental footprint while maintaining an appropriate performance level.

Trials to produce asphalt at 105^{o}C and at a 60 % recycling level have met the performance criteria for conventionally produced asphalt.

Keywords: Low Temperature Asphalt, Shell WAM Foam, recycling, homogeneity, CO2

1. INTRODUCTION

The two key developments in reducing the environmental footprint of asphalt roads can be summarized as: ***recycling*** and ***lowering the production temperature of road asphalt mix***. Significant progress is being made in both areas separately. However, developments in combining both techniques are lagging, the result of technological complexity. As will be explained below, both concepts even conflict with each other. But they do not conflict in regards to the desired objective of improving the environmental footprint of asphalt roads, while maintaining high end quality, a condition for long lasting roads.

This paper describes a system with which this combined development objective can be achieved. First, the technological problem is analysed and the development requirement of the new Shell WAM Foam process with RAP is defined. Then the total development including laboratory work up to full scale works are presented.

2. THE TECHNOLOGICAL QUANDARY

2.1 Lowering of the production temperature

A conventional asphalt mixture is produced at the temperature associated with the viscosity of the binder (EVT), usually 150 to 170 ^{o}C. This temperature is required for the following reasons:

- With production: the homogeneous mixing and coating of all mineral parts to the smallest filler granule with bitumen.
- With processing: plasticity of the asphalt mixture for the spreading and compaction of the asphalt layer on the road.

A technique to lower production temperature must offer a solution to both requirements.

2.2 Re-use of old asphalt in new asphalt

Old asphalt consists of granulates in which all asphalt components are present: mineral parts bound together by the old binder. This old binder is generally hard and brittle due to aging, and generally has a higher viscosity (EVT) than the new binder to be added. It then becomes increasingly important that the old asphalt aggregate fully melts, and in the (typically short) mixing times used is blended homogeneously with the new construction materials. The presence of hard, aged binder in the recycled asphalt aggregate means a higher production temperature than would be the case if only virgin materials were used.

Both techniques applied together (low-temperature asphalt + recycling) result in a potential conflict: the desired lowering of the production temperature means the granules of the old asphalt do not melt fully in the short mixing time in the asphalt plant, leading to a non-homogeneous end product. Therefore, the required complete mixing of the old binder with the new bitumen does not take place. In particular the fatigue properties of the end product will be negatively influenced, resulting in shorter service life. Fatigue is a particularly important property of base layers, since it is exactly in these layers that the highest percentages of RAP are used.

3. TECHNIQUES FOR LOWERING PRODUCTION TEMPERATURE

Many techniques are applied worldwide to lower the asphalt production temperature. These are not all covered within the scope of this paper. In general, techniques based on bitumen foaming are successful and are already widely used. Two specific techniques based on foamed bitumen are discussed below, as are their abilities to meet the aforementioned problems.

3.1 Foamed bitumen

With this technique the viscosity of the newly to be added binder apparently decreases and the volume is increased by foaming the bitumen with a small quantity of water. Then the coating of the mineral parts can take place at a lower temperature. The low quantity of moisture in the mixture also ensures the necessary workability of the asphalt mixture on the road.

However, this technique does not offer any solution to the recycling of old asphalt. The binder from the old asphalt is not foamed, and at the lower mixing temperature the temperature required for the melting and disintegration of the old asphalt part is not reached. This will cause a certain non-homogeneity, which increases as the share of old asphalt becomes greater.

3.2 The Shell WAM Foam [1] technology

With this technique [1], a very soft bitumen is added in the first phase of the mixing process. At the lower production temperature this binder ensures good coating and adhesion of the mineral parts. A hard binder is added in the second mixing phase using the foamed bitumen technique that mixes well with the pre-coated mineral. Both binders together ensure the desired total quantity of binder in the required hardness by mixing. A better end quality is achieved with the pre-coating in this two-phase process than with the normal foamed bitumen production process.

In principle, however, this technique doesn't provide a solution to the recycling of old asphalt. If old asphalt is added, the particles of old asphalt disintegrate less well at the lower production temperature, and the risk of inhomogeneity ensues particularly with higher recycling percentages. The Shell WAM process, however, does offer the key to solving this technologically challenging problem. This solution is presented below.

4. THE NEWLY DEVELOPED PROCESS

4.1 The purpose: reduced environmental footprints of asphalt roads

The lowering of the production temperature and the re-use of old asphalt have a shared purpose. Besides the economic advantage of recycling, both techniques result in an improved environmental footprint of the end product. But can these techniques be assessed in the light of each other? In other words: if the desire for a lower production temperature has the consequence that a lower percentage of old asphalt must be used, is the net effect still positive? To answer this question it is necessary to quantify the effect of both techniques. This can be done by calculating the effect on CO_2 equivalent emissions. Here it is assumed that a technique can be used– with the preservation of the final road asphalt quality – to lower the asphalt mix production temperature in combination with a high recycled content (60% by mass of final asphalt mix). This technique is provisionally called: the newly developed Low Temperature + High RAP Process (LTHRP).

Using a Life Cycle Assessment (LCA) approach, a "cradle-to-gate" study has been made to assess the energy required for and the airborne emissions related to the use of the LTHRP (i.e. WAM + RAP), compared to the conventional Hot Mix Asphalt (HMA) and HMA with the use of RAP. This internal study examines the environmental performance resulting from the sourcing, transport and mixing of the asphalt mixture ingredients to the point where the mixed product leaves the gate of the mixing plant.

The base case for this study is HMA produced in a modern efficient natural gas-fired batch plant operating in the Netherlands with a "short" supply chain for most of the ingredients. "Short" in this context means that the materials are from sources within a range of 150 kilometres.
The use of different fuels (natural gas, LPG and fuel oil) does not change the conclusions for the comparison of the five asphalt scenarios. Although the fuel types have different emission patterns per unit of energy, the trends are the same for all fuel types.

It is obvious that the lowering of the production temperature has an immediate positive effect on fuel consumption for the drying and heating of the new minerals (sand and stone) and of the old asphalt. For the LTHRP, the mixing temperature is 105 ºC and the new minerals and old asphalt are heated to 100 ºC and 120 ºC respectively with both 30 and 60 % recycling. It is not desirable to further lower the temperature of the new minerals otherwise the drying process would not be complete and the remaining moisture could negatively affect the pavement durability.

A higher percentage of RAP also has a beneficial effect, because gas consumption per tonne of product from the drying drum (new minerals) is higher than gas consumption per tonne of product from the parallel drum (old asphalt).Indeed the moisture content of RAP is on average less than that of the combined sand and stone fraction, in particular because of the higher moisture content of the sand.

Table 1 shows a translation of the different mixes and operating conditions into energy use and greenhouse gas (GHG) emissions performance. From this Table, it can be concluded that relative to the HMA base case without RAP, improvements in environmental performance occur for HMA with increased amount of RAP. A difference of about 10% in favour of the LTHRP (WAM+RAP) can be seen for both RAP percentages in comparison to HMA with RAP when comparing the energy and GHG indicators. Energy in this table is expressed in second order of energy, which is energy consumption including the energy requirements for the production and distribution of the fuel. It therefore includes both direct and indirect energy consumption.

[1] "WAM" is a registered trade mark of Shell Brands International AG

Table 1: **Energy and GHG performance indicators for all five asphalt types, cradle-to-gate, using natural gas, per metric tonne of asphalt mix produced**

Energy and GHG	Energy MJ	%*	GHG emitted CO_2eq [kg]	%*	Energy MJ	%**	GHG emitted CO_2eq [kg]	%**
HMA	948	100	58.4	100	XXXXX		XXXXX	
HMA+RAP25	825	87	50.6	87	825	100	50.6	100
WAM+RAP25	742	78	45.7	78	742	90	45.7	90
HMA+RAP50	625	66	38.2	65	625	100	38.2	100
WAM+RAP50	556	59	34.2	59	556	90	34.2	89

*With HMA as 100% ** HMA vs WAM with different levels of RAP

The energy used for hot mixing (especially for drying and heating the minerals and RAP) and the binder used in the mix are the dominant factors for energy. For GHG-related impacts, the dominant factors are the energy-related emissions and the binder.
So besides lowering the production temperature, re-use of old asphalt will have a beneficial effect in particular because of the savings on new bitumen. Obviously with re-use the savings on primary minerals and the shorter transport distances also make a contribution.

Figure 1 shows the effect on CO_2 equivalent emissions in relation to the recycling percentage for the (conventional) re-use of old asphalt (blue line) and for the application of the LTHRP (red line). Both lines are extrapolated to 60 % recycling as this amount of old asphalt is customary in the NL.

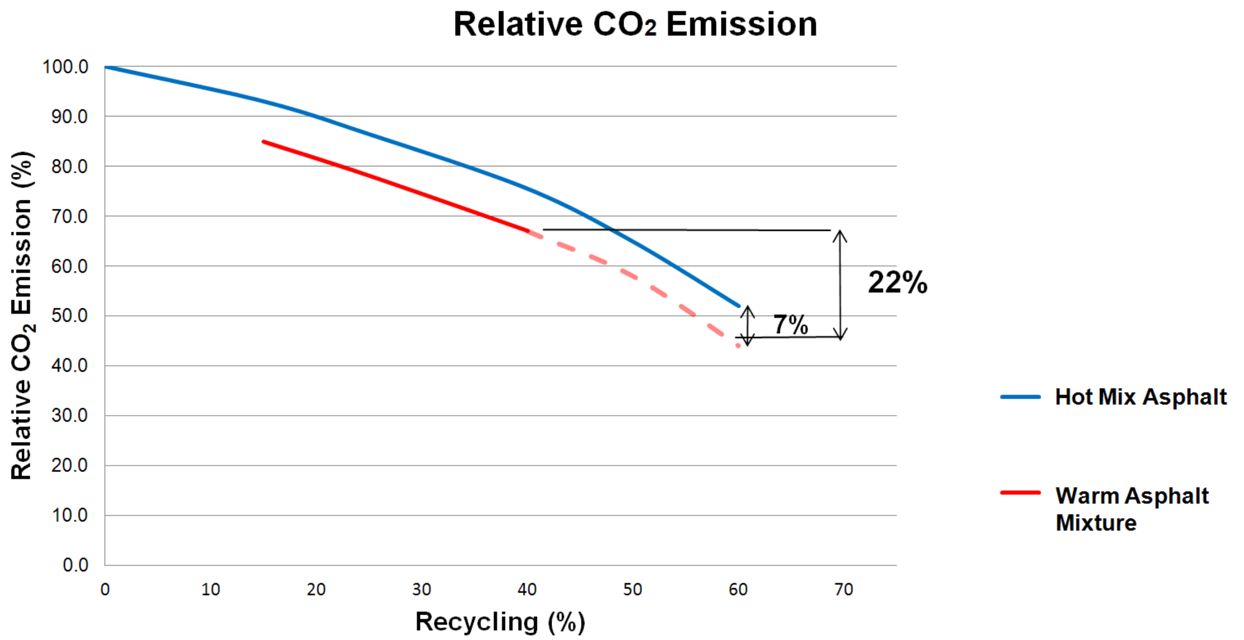

Figure 1 : Relationship between CO_2 equivalent reduction and RAP percentage for HMA and LTHRP

Table 2 shows the calculated heat consumption directly related to the heating and drying process in the asphalt plant for all technologies. The LTHRP shows a significantly better performance, a reduction in energy used of about 25% compared to the HMA with RAP alternative with the same amount of RAP and 30-35% compared to HMA.

Table 2 : Energy requirements for the asphalt mixing plant per metric tonne of asphalt mix produced

(natural gas LHV = 31.65 MJ/Nm^3)	HMA	HMA 25% RAP %wt.	WAM 25% RAP %wt.	HMA 50% RAP %wt.	WAM 50% RAP %wt.
Heat MJ	285	270	197	247	188
Nm^3 natural gas equivalents	9.0	8.5	6.2	7.8	5.9
%heat requirement to HMA	100%	95%	69%	87%	66%
%heat requirement to HMA with RAP	XXXXX	100%	73%	100%	76%
Electricity kWh	3.40	3.40	3.40	3.40	3.40

Figure 2 shows the relative differences in energy consumption for heating and drying in relation to the recycling percentage for the different technology variants.

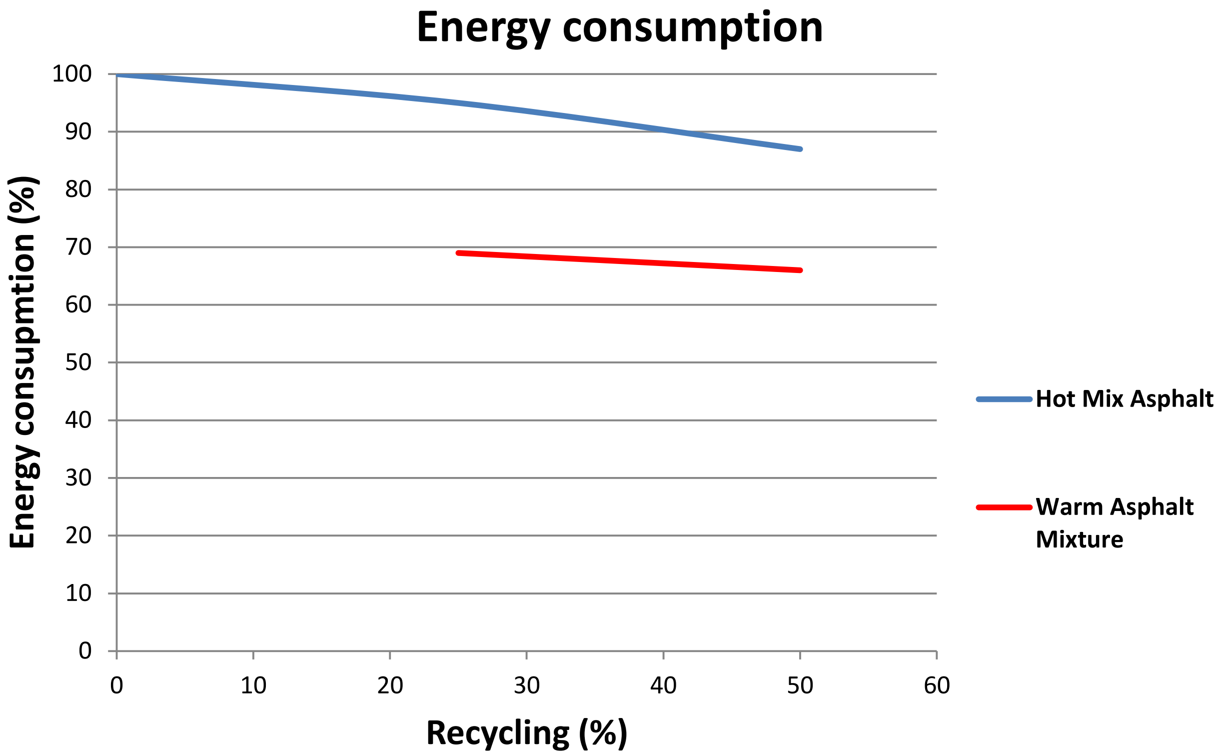

Figure 2 : Relationship between energy consumption in the asphalt production process and recycling percentage for conventional HMA and LTHRP

Both figures clearly show that a reduction of the recycling percentage in order to enable the production at a lower temperature is **counterproductive**.
Due to the reduction of the production temperature the recycling percentage is reduced to 40%, which means that the potential GHG reductions are reduced by 15% relative to the extrapolated estimate of emissions reductions at 60% RAP content. This reduction in environmental performance is not compensated by the CO_2 effect of the lower fuel consumption in the mix plant.
With this knowledge the starting point for the newly to be developed production process could be clearly established:

> ***A technique to lower the production temperature by which a high quality equivalent asphalt mixture can also be produced with high recycling percentages.***

4.2 The procedure of the new process

To achieve the set objective: "lowering the production temperature with a high share of recycling" a method is developed whereby the RAP is pre-processed. This pre-processing takes place "online" in the asphalt plant and makes use of parts of the plant already in place. A batch-mix asphalt plant already designed for the addition of a high share of old asphalt is used as a starting point. A parallel drum is used here, which in addition to the main drying drum for the new minerals ensures the heating of the old asphalt.

After this heating, usually to 110 to 120 ^{o}C, the old asphalt is customarily taken to a warm intermediate bunker where it is stored for a while before being dosed in the plant's mixer. In this mixer, the heated old asphalt together with the somewhat overheated new mineral and the new bitumen to be added, are mixed so a homogeneous final mixture is obtained at the customary final temperature of 160 to 170 ^{o}C. The newly developed technique makes use of the same parts of the asphalt plant, with only two components being added.

4.2.1 Injection provision in the parallel drum

An injection lance can be used to inject a soft binder into this drum. By doing this in the right place (a certain distance from the run-out of the drum) the heated asphalt aggregate is coated by the binder. This very soft binder has a penetrating effect on the asphalt aggregate. As a result, at the final temperature of the parallel drum (approx. 120 ^{o}C) softening of the old asphalt granulate occurs. This process requires some time. The warm bunker is used for this. By keeping this bunker maximally full, a storage time of approx. 10 min. is achieved. After this softening process the treated asphalt aggregate is dosed into the mixer, and in a first phase mixed with the coarse fraction of the new mineral, that is heated to approx. 100 ^{o}C. This process causes the old asphalt to fully disintegrate at the lower temperature in the original construction materials.

4.2.2 Foam bitumen installation

The second component to be newly added is a foam bitumen installation at the mixer. See also Figure 3. Here the newly to be added binder is injected in the mixer as foamed bitumen. Then at a final temperature of 105 to 110 ^{o}C the last phase of the mixing process can be completed. With these two additions a homogeneous final mixture is obtained by using the existing asphalt plant in a controlled way, while the advantages of the original Shell WAM foam principle are retained. The processing properties appear to be particularly positively influenced by the lubricating effect of the soft binder. More about this later.

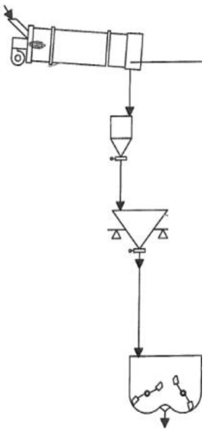

Figure 3 : Foam bitumen installation schematics

4.3 The result

The final mixture is formed from the following construction materials:

- Minerals and filler from the old asphalt
- Newly added mineral
- Newly additional filler
- Binder from the old asphalt
- Soft bitumen injected in the parallel drum
- Newly added binder by means of foamed bitumen

With sufficient information about the composition of the old asphalt and a matching selection of new construction materials to be added, the desired composition of the end product can be obtained in a controlled way. Here it is important that the quantities and the hardnesses of the different binder components are carefully matched so the desired final hardness of the binder is also obtained.

An important factor that has in the meantime appeared from practice is the following: With the considerably lower production temperature no hardening of the binder occurs as a result of oxidation during the production process. The theoretically calculated final hardness of the binder has also been found to be exactly obtained, while with conventional hot asphalt production a considerable drop in the penetration value of the binder occurred. This is also of importance for the mechanical properties of the end product. More about this later.

5. LABORATORY STUDIES

An extensive laboratory study programme was executed mainly at Heijmans laboratory in Rosmalen for the development of the process described above. All stages and all effects were separately investigated. A complicating factor here is that ***time-related*** effects occur in a number of essential process steps in the production process.

Accordingly, the coating of the old asphalt with the soft binder and the following softening process are time-related. The final mixing of all components, the phasing of this and the injection of the bitumen foam are also time-dependent processes. This has the consequence that for a good study in the laboratory replicas of the parts of the production process must be available. In fact, the whole route travelled by the material flow in the asphalt plant must in essence be replicated to scale in the laboratory. Figures 4, 5 and 6 show the several constructed lab-components:

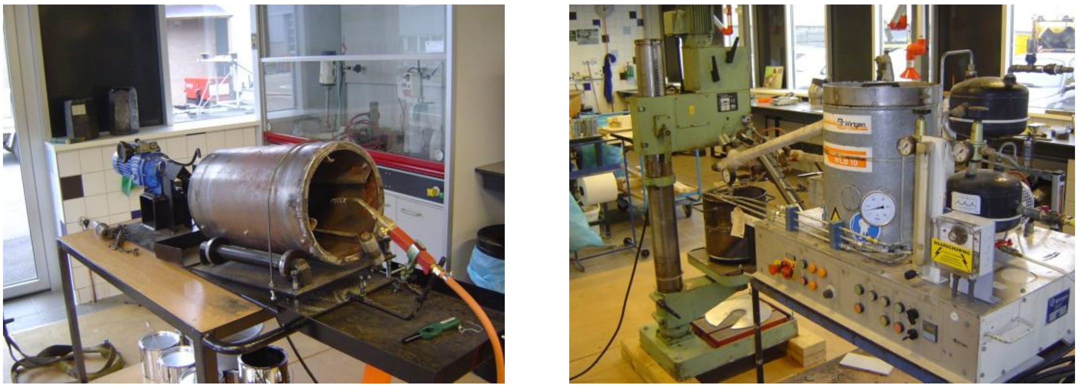

Figure 4 : Lab drying drum [left] and Foamed bitumen installation at the final mixer [right]

Figure 5 : RAP – Cold [left], heated to 120°C [middle], heated and softened (soft binder) [right]

Figure 6 : Mixer [left], mixing bowl [middle], well-coated homogeneous final production at ± 110°C [right]

5.2 Optimizing laboratory process

In the laboratory an optimisation process takes place and the end result is assessed by the spontaneous disintegration of the old asphalt in the original construction materials. In Figure 5, it is clearly observable that with this pre-treatment process the old asphalt aggregate already largely spontaneously disintegrates into the original components.

The laboratory varied the mixing order and mixing times in order to optimise the coating and homogeneity. It appeared that the best result is obtained when the pre-treated, softened asphalt aggregate is mixed in a first phase with the new, coarse mineral (the stone fraction). Then the last residues of the asphalt part of the old asphalt fully disintegrate, and pre-coating of the new mineral takes place with the soft binder from the pre-treated old asphalt. Then the other new mineral, the filler and the foamed bitumen are introduced in the mixer. The post-mixing phase then follows with a fully homogeneous and well-coated final mixture as a result.

This end product, see also Figure 6, requires no addition of additives or chemicals to improve coating or adhesion. It contains the same components as the comparable hot mixture. Only the binder has a different composition, and only with bitumen components.

6. END PRODUCT PROPERTIES

The general name of the end product produced according to this new procedure is called: **Greenway LE** (LE = Low Energy). Greenway LE is a registered trade mark of Heijmans – Breijn.

Table 3 : End product properties overview – normal asphalt versus Greenway LE

	European Standards	Traditional asphalt 170 °C, with 60%recycling	Greenway LE 110 °C, with 60%recycling
Compactibility	EN 12697-31	2.9 E-04 1/mm	2.7 E-04 1/mm
Void content	EN 12697-08	5.5%	4.5%
Water sensitivity [ITSR]	EN 12697-12	75%	82%
Penetration binder after recovery 0,1 mm	EN 1426	30	45
Indirect tensile strength	EN 12697-23	3.0 MPa	2.2 MPa
Resistance to permanent deformation fcmax	EN 12697-25	0.55 μm/m	0.8 μm/m
Stiffness	EN 12697-26	10586 MPa	8327 MPa
Fatigue resistance ε6	EN 12697-24	95 μm/m	111 μm/m

Final mixtures are produced in the laboratory according to the new process, whereby the HMA is also produced for purposes of comparison (see Table 3). For a number of mixtures the complete (mechanical) test programme according to the European standards was also carried out. The following are the results for an asphalt mixture commonly used in the Netherlands: AC 16 base 40/60 60% PR. This concerns a mixture for base layers in which 60 % old asphalt is used.

Here is a brief consideration of all the properties reported in Table 3:

- Compactibility is measured according to the Gyrator compaction method. Here the number of rotations is shown per mm drop in the compacting device. The compactibility of the Greenway LE mixture is a fraction lower than the hot reference mixture. In practice slightly higher compacting energy will therefore theoretically be required - the difference will not or barely be noticeable.
- The void content at the end of the compaction process for the Greenway LE mixture is less than for the reference mixture. This appears in contradiction of the slightly worse compactibility. However, the binding and lubricating effect of the soft binder may mean that the compaction process can be continued. The end quality is then positively influenced.
- According to the Indirect Tensile Strength Retention [ITSR] method, the water-sensitivity of the Greenway LE mixture was found to be less than that of the reference mixture. This is very surprising: a mixture produced and compacted at a lower temperature would be expected to have greater water-sensitivity. This unexpected effect was observed with a number of tests and with a number of mixtures; also with cores taken from field trials. The explanation of this positive effect must be sought in the pre-coating with the soft binder. This primer effect provides protection against moisture penetration on the mineral surface.
- The penetration value of the recovered binder in the end product is a result of the different binder components from the construction materials: old asphalt, soft binder and bitumen foam. A value can be predicted when the penetration or the viscosity of the base components are known. With conventional asphalt production there is, however, another important factor: the hardening of the binder during production as a result of oxidation. During the mixing process the binder is spread over a large mineral surface where it is exposed to oxygen at high temperature. This causes oxidation. For example: with the addition of a new 45 pen bitumen in a HMA without recycling, the penetration value can drop to 30 as a result of the oxidation process. With the Greenway LE mixture, the quantities and hardnesses of the additional binding agents are selected in such a way that a target penetration of 45 would be obtained (without hardening effect). This value is also found with the binder recovered from the end product. So in general no hardening occurs here.
- The relatively high value of penetration in the end product, compared with the reference mixture, does have consequences for the mechanical properties. The splitting strength, the resistance to permanent deformation and the rigidity of the Greenway LE mixture are slightly less than that of the reference mixture. This is also attributable to the higher penetration value of the resulting binder. Mixture optimisation took place for this as this is undesirable, see below.
- The fatigue properties of the Greenway LE mixture are better than those of the reference mixture, also caused by the softer binder. This can be beneficial when use is made of the Greenway LE mixture as a base layer in an asphalt construction. Indeed, the fatigue properties of the base layers largely determine the life of the asphalt construction. The highest tensile stresses occur in this layer with loading while permanent deformation is less important for this layer.

The Greenway LE mixture described above is therefore highly suitable for application in the base layer of an asphalt construction, while for the higher layers a mixture with better resistance to permanent deformation is required.

The purpose is therefore to reduce the penetration value of the resulting binder. The system offers good adjusting options for this, as two binders with a different hardness are added in the process.
Adjusting the ratio between the soft binder and the binder for the bitumen foam slightly can alter the desired final hardness.

This optimisation was carried out aiming for a binder penetration of 35. Some mechanical tests have already been carried out with the mixture obtained in this way. The resistance against permanent deformation was obtained at a significant better level: 0.4 µm/m. At this level the mixture complies with the highest load standard for application in Dutch motorways.

In the meantime a study was carried out at Rosmalen laboratory on a top layer mixture based on the Greenway LE process. This concerns an AC 11 surf 50/70 30% PR. The initial results confirm the picture above: the water-sensitivity is not negatively influenced, and the mechanical properties are comparable with the conventional, hot produced mixture.

Additional laboratory tests were conducted at Nottingham University (UK) to establish whether a curing effect occurs with asphalt mixtures produced according to the Greenway LE process.
A curing effect leads to ‘hardening’ of the processed product decreasing over time. Both the presence of residual moisture in the mixture originating from the bitumen foam as well as the presence of different components in the binder can cause this ‘hardening’ effect.

From the results it can be concluded that a curing or further hardening effect indeed occurred. This is not observed in conventionally produced HMA. This is a favourable effect, as quality is usually assessed immediately after laying. This curing effect means the product offers an additional strength of approximately 10 %.

7. PRODUCTION TESTS

In 2010, trial production runs using the LTHRP were conducted at the contractor Heijmans asphalt plant in ‘s Hertogenbosch (the Netherlands): injection of the soft binder in the parallel drum and a foamed bitumen unit by the mixer. No problems occurred with the construction of either provision. The provisions were connected to the plant’s control system so dosing could be matched with the production capacity. See also Figure 7.

Figure 7 : Asphalt plant – Injection in parallel drum [left], foamed bitumen unit by the mixer [right]

Various test runs took place with different asphalt mixtures. The result is visually assessed for coating and homogeneity. The positive findings of the laboratory research concerning the working of the Greenway LE process were confirmed here. The final temperature of the asphalt mixture was always between 105 and 110 ^{o}C.

8. FIELD TRIALS

8.1 General

A number of projects of increasing size were executed by Heijmans in 2010 and 2011. Cores were drilled from the compacted asphalt, which were compared with the material manufactured in the laboratory. The compaction, void content, composition, splitting strength and water-sensitivity of this production were determined. In general we can say that the results are in correspondence with the properties determined in laboratory investigation as reported before.

8.2 Production

It was clearly observable during production that less bitumen vapour is produced when loading the trucks than with conventionally produced asphalt. Or there was no bitumen vapour at all, see also Figure 9 [left].

Figure 9 : Asphalt plant – truck loading [left], heavy transport on freshly laid Greenway LE asphalt [right]

8.3 Energy consumption

Gas consumption per tonne of end product was recorded for a number of projects at the mixing plant of ‘s-Hertogenbosch. For an AC 22 base LE mixture with 60% RAP the gas consumption is between 5.8 and 6.3 m³/tonne, depending on the weather conditions.
With conventional hot asphalt production with the same RAP share, gas consumption amounts to an average of 8.2 m³/tonne. This shows in practice that the expected reduction in gas consumption of 25% is indeed achieved.

8.4 Application

Several characteristic aspects were observed when applying the Greenway LE mixture:

1. No differences are observed compared to the conventional mixture with machine application. With handwork the Greenway LE mixture is experienced as somewhat stiffer.
2. Compaction can take place immediately behind the spreader with heavy rollers. The best effect is obtained with triple-roller rolling.
3. There is a large difference with the conventional mixture, in which only limited compaction is initially possible particularly with thick layers. A thick layer of hot asphalt is too unstable to exert full compacting energy. The maximum compacting energy can immediately be exerted on the Greenway LE mixture.
4. This effect means compacting is also completed earlier. The roller operators consider it favourable that application and the compacting process can take place within a shorter interval. This is particularly the case if one has to move from the one location to the other.
5. The layer can also be loaded sooner, because the asphalt layer has a considerably lower temperature. At one site heavy transport (concrete mixer) was ready to drive on the layer that had just been laid. The truck used the asphalt hardened surface immediately after the last roller pass (Figure 9 Right). No rutting was observed.
6. A number of asphalt layers can also be laid on top of each other in a shorter time for the same reason. The spreader can drive back over the layer that has just been laid and the cumulation of the heat of a number of layers on top of each other is lower.
7. The mixture also appears less likely to crack with an unstable surface. This is due in part by the more equal temperature in the layer. With conventional hot produced asphalt the difference with the outdoor temperature is greater so the asphalt surface cools more quickly. The compacting route is also longer. This means the surface of the new layer is already hard, particularly with an unstable subsurface, so much deformation still occurs when the roller passes. This causes cracks in the top of the layer. This effect is not observed with Greenway LE.

The experience described above has led to the favourable introduction of Greenway LE asphalt in practice. Larger applications are being prepared.

9. CONCLUSIONS

The following conclusions can be drawn from the R&D work on the newly developed process described above:

1. Pre-treatment of old asphalt with a soft bitumen before having it stand in a warm bunker for a while at a relatively low temperature (approx. 120 ^oC) results in the disintegration of the asphalt aggregate into the original construction materials.
2. Transfer during the mixing process of the soft binder from the processed old asphalt to the new mineral results in the better coating of the mineral at lower temperature (approx. 100 ^oC).
3. Addition of (harder) bitumen foam in the last mixing phase in combination with the soft binder earlier added results in better coating and homogeneity of the end product (Shell WAM foam experience).
4. Lowering the production temperature of asphalt results in considerable fuel savings and as a consequence lower CO_2 equivalent emissions.
5. Recycling old asphalt means a considerable reduction in CO_2 equivalent emissions. Reducing the recycling percentage to be able to produce at a lower temperature works counterproductively
6. With the newly developed process (LTHRP), a high recycling percentage (60 %) can be combined with a low production temperature (110 ^oC).
7. Experience with the production of Greenway LE mixture confirms the results of the laboratory research: mixtures can be produced with quality comparable to conventional, hot produced mixtures. With large production runs fuel reductions are measured of approx. 25%.
8. No chemical additives are required.
9. Handwork during laying is somewhat heavier, but the compaction options are comparable with or even better than HMA. The compaction of the asphalt layer takes less time and a new layer can be applied sooner. The road can also be opened to traffic sooner.

REFERENCES

[1] B.G. Koenders, D.A. Stocker, C. Bowen, O. Larsen, D. Hardy and K.P. Wilms: “Innovative process in asphalt production and application to obtain lower operating temperatures”, 2nd Eurasphalt & Eurobitume Congress, 2000.