Successful Dutch Experiences with Low Energy Asphalt Concrete

M.M.J. Jacobs, C.M.A. van den Beemt en B.W. Sluer
BAM Wegen bv, Department of Technology and Development (T&O), Utrecht, the Netherlands

ABSTRACT: In this paper attention is paid to the successful development and application of a low energy or half warm asphalt concrete approach in the Netherlands. This product, called LEAB, has become a popular product in binder and base layers due to the fact that about 40% energy and about 25% CO_2 reduction can be accomplished compared to the same hot produced asphalt mix. And this without loss of functional mix properties. These environmental friendly properties are achieved because LEAB is produced at a temperature around 95-100°C.

The main difference with other half warm asphalt concrete concepts is the fact that LEAB can be produced both in the laboratory and in an asphalt plant with the same functional specifications as a comparable hot mix with the same mix composition. With this concept, it is possible to optimize LEAB on laboratory scale and to apply the LEAB-principle to other asphalt concrete mixes like surface layers, SMA and/or porous asphalt.

In this paper the development of the LEAB concept is summarized. Attention will be paid to specific characteristics of LEAB. Items as the development of a foam device on laboratory scale and in an asphalt plant are discussed. Also results of various comparisons will be presented between the performance based properties of LEAB and a similar hot asphalt mix, both produced and compacted in the laboratory and in asphalt plants. Here items like water sensitivity, stiffness and resistance to fatigue and permanent deformation will be discussed. Finally, also results of an extensive study on the environmental properties of LEAB will be presented using the Dutch standard NEN 8006.

KEY WORDS: Half warm mix, foamed bitumen, functional mix properties, environmental properties, CO_2-reduction.

1 INTRODUCTION

Climate and sustainability issues are increasingly being given priority by government bodies. Although asphalt is perhaps not the first product that comes to mind in connection with sustainability, low-temperature asphalt and sustainability can actually go very well together. For this reason the use of warm mix asphalts (WMA) is very popular and various kinds of WMA-products are developed. In table 1 an overview of various WMA-products is given. Also information on the kind of production process and the mixing temperature of the product is given.

Table 1: Overview of various WMA procedures (D'Angelo et.al, 2008).

WMA Technology	Process Type	Production temperature
Advera	Additive/foam	120 – 140°C
Aspha-min	Additive/foam	130 – 140°C
Cecabase RT	Chemical additive	120 – 130°C
Double Barrel Green	Foam	120 – 140°C
Evotherm	Chemical additive	110 – 130°C
LEAB	Foam	90 - 110°C
LEA-CO	Foam	80 – 130°C
LT-Asphalt	Foam	90 - 110°C
Rediset WMX	Chemical additive	130 – 140°C
Sasobit	Organic additive	130 – 140°C
Stansteel	Foam	120 – 140°C
Synthetic Zeolite	Foam	130 – 140°C
Terex	Foam	120 – 140°C
WAM-Foam	Foam	120 – 140°C

With its LEAB® (Dutch acronym for: Low Energy Asphalt Concrete), BAM Wegen shows that a decision to opt for low-temperature asphalt does not necessarily has an effect on the durability of the resulting product. As a matter of fact, the stiffness characteristics as well as the fatigue resistance and susceptibility to rutting of LEAB are equivalent to that of hot mix asphalt. In recent years, experience has been gained with the production and processing of LEAB, which has been very positive. As a result, the authorities responsible for the national, provincial and rural road networks can now also demonstrate their concern for the environment within the framework of new road construction.

In this paper attention will be paid to the characteristics of LEAB. The principles behind the LEAB mix will be discussed. The mechanical properties of LEAB will be compared to the traditional hot mix. Finally the environmental advantages of LEAB will be discussed.

2 THE BACKGROUND OF LEAB

A standard 70/100 penetration bitumen is used for the production of LEAB. However, the main difference is that the temperature remains below 100°C during the production and processing of LEAB. In order to realise a sufficiently low viscosity of the binder (which in turn makes it possible to effectively coat the mineral aggregate), the binder is added as a foam. The principle of using foamed bitumen is not new (Csanyi, 1957) and has been used for some time in road construction in order to produce road bases and pavements. However, due to the expiry of several patents, the use of foamed bitumen technology for building asphalt roads has gained increasing popularity in the last two decades.

The composition of LEAB is almost identical to the standard hot mixed asphalt concrete for base layers, produced at ±165˚C (Dutch acronym: StAB). This implies that for producing LEAB, standard non-porous mineral aggregates are used. These aggregates and also the sand (with a maximum of 3 %m/m of fines) are heat up to 95°C. In this way, almost all water has been evaporated from the aggregates. The only extra component in LEAB is the use of an additive to ensure that the quality of the foamed bitumen is maintained over a longer period of time. The additive results in a high expansion value and, in particular, a long half-life for the foamed bitumen. In fact the additive neutralizes the anti foaming agent which is put in the bitumen to prevent foaming of the bitumen during transport and the mixing process of asphalt concrete. It is emphasized that a longer half-life of the foamed bitumen does not influence the curing time of the mix: in fact, with LEAB no curing time is needed at all. Almost immediately after compaction, LEAB has the same mechanical properties as a hot mix has. For LEAB a longer half time results in a longer time period between production and compaction of the LEAB. So the characteristics of the additive are very important to realise an effective coating of the mix and ensure that the mix being produced can be worked with for a longer period of time.

For years, it was assumed that it was necessary to introduce extra liquid into the mixture to ensure that the foamed bitumen was effectively distributed throughout the mixture (Jenkins, 1999; Jenkins et al., 2000). However, based on recent experiences, one may conclude that this is not necessary, and even not desirable, in relation to the present production process for LEAB.

Another remarkable property of LEAB it the fact that it is possible to use reclaimed asphalt in the mix. In the Netherlands, a recycling percentage of 50% is normal. At a 50% recycling percentage, the functional characteristics (stiffness, resistance to fatigue and permanent deformation) of LEAB remain the same as for the hot-mix asphalt with the same mix composition . A typical mix composition of a LEAB mix is given in table 2.

Table 2: Mix composition of LEAB

Constituent materials	Mass percentage
Crushed aggregate 8/16	19,3
Crushed aggregate 16/22	9,7
Natural sand 0/2	17,8
Filler	0,4
Baghouse dust	0,7
Reclaimed asphalt 0/20	50,4
Bitumen 70/100	1,7
Total	100

3 THE PRODUCTION OF LEAB

Since 1998, BAM Wegen has been carrying out research in order to master the issues associated with foamed bitumen and to modify it for practical use. A research project financed by the government was carried out which took almost four years and was realised in cooperation with the Technical University of Delft and the University of Stellenbosch in South Africa. The research project was a success, but initial attempts to upscale the results obtained in the laboratory to a practical scale proved to be very difficult. However, after several unsuccessful experiments, a procedure was finally developed which turned out to be very successful! As a result, almost all the theories previously developed became outdated and mixing procedures had to be rewritten.

Not withstanding the usual research procedure, LEAB was first produced successfully in practice in a standard asphalt plant and not in the lab. The main reason for this is that in a standard road engineering laboratory, the mixing capabilities to produce a proper mix are limited. In most cases, the mixing energy is limited and mixes with foamed bitumen are very vulnerable for this phenomenon. For this reason a new mixing machine was developed, which is almost identical to the mixing process in a asphalt plant. With this mixer (see Figure 1) it is possible to produce in the lab a half warm mix with the same properties as in a standard asphalt plant. This unique development opened the way to optimize the foaming procedure of the bitumen and the half warm mixes. In this way not only half warm mixes for base layers or binders, but also mixes for surface layers can be developed in the lab. It is expected that even SMA and porous asphalt can be produced with the half warm procedure, both having the same functional properties as the hot produced equivalents.

Figure 1: Lab mixer and foam unit to prepare a half warm mix in the lab

The point of departure for the research project was the production of high-quality asphalt concrete in a conventional asphalt plant according to the foamed bitumen concept, without having to make large-scale investments in or make changes to the production facility. In the end, this resulted in the construction of a foamed bitumen generator in one of the asphalt plants of BAM Wegen, which could replace the present hot-mix bitumen dosage system. However, it is not the foam bitumen generator and dosage unit that are critical to the success of the project. The procedure and treatment of the constituent materials are.

BAM Wegen has now already fitted two asphalt plants with a foamed bitumen unit (see Figure 2), making it possible to produce LEAB on a large scale. The two plants include a batch-process based facility (batch mixer) and a continuous production facility (double drum mixer), which justifies the conclusion that the production process developed by BAM Wegen can be applied on quite a large-scale. As mentioned previously, this opens up opportunities for developing more environmentally friendly asphalt mixes incorporating the use of foamed bitumen, which in turn can lead to a more sustainable infrastructure.

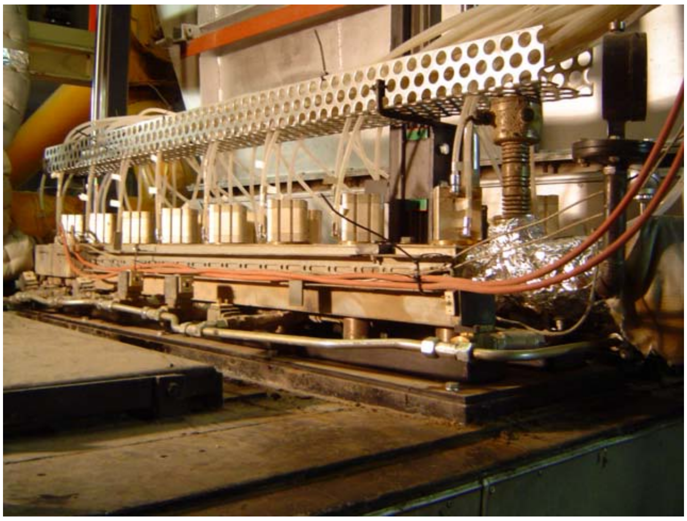
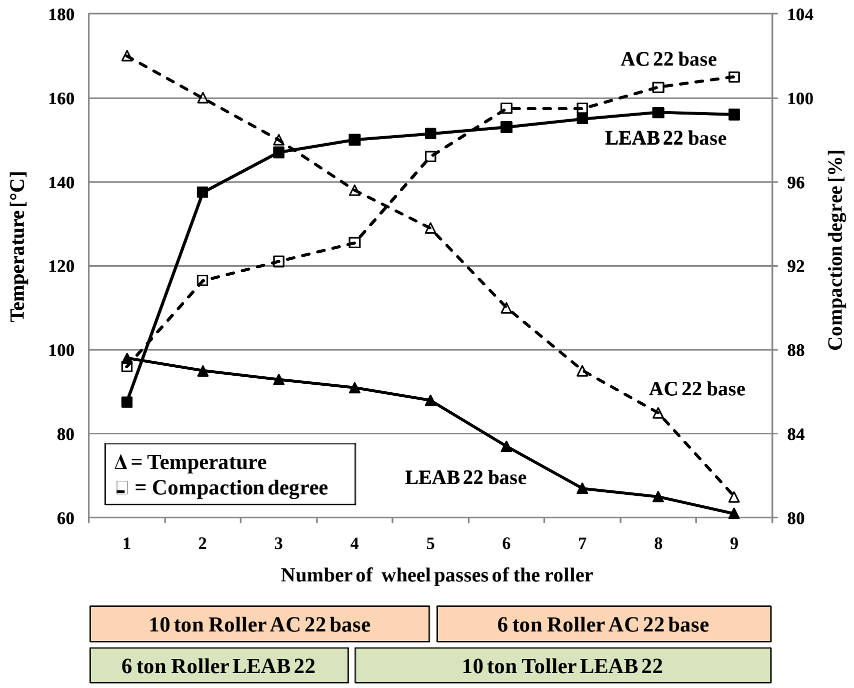


Figure 2: The beam with foam nozzles in an asphalt plant

4 THE COMPACTION OF LEAB

The workability and compaction of LEAB has never been a problem. The product can be applied using standard pavers and rollers. One of the differences between the hot and half warm mix is that during compaction, the rollers can not use vibrational compaction: all compaction must be carried out with static rollers. Despite this difference a compaction degree of 100 % can be achieved for the half warm mix with less roller passes than for the hot mix. The asphalt roller operators even state that the half warm mix is much easier and quicker to compact than the hot mix. In figure 3 the compaction process of LEAB and a hot mix is given schematically.



LEAB can be compacted at temperatures between 55 and 90°C. The mechanism behind this relative low compaction interval (the compaction process of the hot mix ends at about 80°C) is until now not yet clear. Maybe the presence of free water or still active foam in the half warm mix plays a role in this relatively low temperature interval for compaction.

Figure 3: Compaction process of LEAB and comparable hot mix

Until now, the maximum period of time between the production of LEAB and its final application has been six hours. However, it is expected that it will be possible to work with and apply LEAB effectively without any problems even after a period of six hours has gone by.

5 THE FUNCTIONAL CHARACTERISTICS OF LEAB

In developing LEAB, the aim has always been to produce an asphalt concrete mix with functional characteristics which are equivalent to those of a hot-mix asphalt concrete with the same mix composition. The best way of demonstrating such equivalence is to do so in a fundamental fashion using the European standards (section 5.4 of EN 13108-1). It must be emphasised here that equivalence on the basis of empirical characteristics (e.g. density, percentage air voids, volumetric and Marshall characteristics) is a much less rigorous comparison and further away from the practical application of asphalt for road-building purposes than equivalence on the basis of functional characteristics. This could be is the reason why some alternative warm temperature procedures like the LEA-CO approach in France, the Nynas LT-Asphalt and Shell's WAM procedure (D'Angelo et.al, 2008) have until now not been as successfully applied in the Netherlands as LEAB.

For a functional comparison, four mechanical properties are analysed: sensitivity to water, stiffness modulus, resistance to fatigue and resistance to rutting:

1. The water sensitivity (one of the general properties in the product standard EN 13108-1) is determined in accordance with EN 12697-12 and 12697-23. In this test the indirect tensile strength (determined at 15°C using a deformation speed of 50 mm/min) of a set of three retained specimens (70 hours in a water bath of 40°C) is compared to a set of three not retained specimens. The ratio in percentage between both mean tensile strength values is a measure for the water sensitivity of the mix;
2. In the Netherlands the stiffness modulus of the mix is determined with the four point bending test (4PB). This test is described in Annex B of EN 12697-26. To determine the stiffness modulus of a mix, 18 prismatic specimens (450*50*50 mm) have to be tested at 20°C and various frequencies (between 0.1 and 30 Hz). The stiffness at 8 Hz is used as the reference stiffness value. The test results are used to compare different materials or as input in a pavement design models;
3. Directly after determination of the stiffness, the fatigue properties of the specimen are determined according to Annex D of EN 12697-24. This displacement controlled test is carried out at 20°C and 30 Hz. To determine the fatigue properties of a mix, 18 specimens are tested. Three deformation levels are chosen in the tests, aiming at a life span of the specimen of 10^4, 10^5 and $2{\cdot}10^6$ load repetitions. Based on the 18 test results, the fatigue line is calculated using the following equation:

$$N_f = k_1\, \varepsilon^{k2} \qquad (1)$$

   Finally the strain ε_6 is calculated where the life span of the mix is 10^6 load repetitions;
4. In the Netherlands, the resistance to permanent deformation is determined by means of the triaxial test according to Annex B of EN 12697-25. In this test four cylindrical specimens are tested at 40°C, using a constant confining pressure of 0,05 MPa and a vertical dynamic stress varying between 0,05 MPa and 0,45 MPa. The vertical load pulse is a haversine with a loading time of 0,4 s, followed by a rest period of 0,6 s. The total test period is 10.000 load repetitions. Finally, the slope of the secondary phase of the relation between the permanent deformation and the number of load repetitions determines the permanent deformation parameter f_{cmax}.

The comparison between the functional properties of LEAB and a hot mix with the same mix composition has been carried out several times in the recent years. Both lab and plant mixed and compacted materials are taken into account. In table 3 results of the comparison between the half warm and hot mix are summarized.

Table 3: Various functional properties of LEAB compared to the reference properties of the hot mix StAB

Year	2005	2007	2008	2008	2009	2009	StAB hot mix (O1-B)
Mixing in	Plant	Plant	Lab	Plant	Plant	Plant	
Compaction in	Road	Lab	Lab	Lab	Road	Lab	
RAP [%m/m]	50	50	50	50	50	50	50
ITS [MPa]	-	2.076	2.696	2.230	-	2.042	-
ITSR [%]	93	96	75	87	-	83	≥ 70
S_{mix} [MPa]	7700	7679	8000	7029	-	7954	≥ 7000
ε_6 [µm/m]	94	97	83	103	-	110	≥ 90
f_{cmax} [µm/m/N]	-	0.43	0.43	0.53	0.41	0.54	≤ 0.4

Also wheel tracking tests has been carried out on the half warm mix. These wheel tracking tests are carried out with the large sized wheel tracking device according to paragraph 6.1 of EN 12697-22. In this device a vertical load of 5 kN is applied using a tire pressure of 600 kPa; the tests are performed at a temperature of 50°C. The number of load repetitions is 30000. In table 4 the results of several tests are presented. Also the results of the reference hot mix and a special developed high stability mix called Kjellbase (Sluer, 2004) are presented.

Table 4: Results wheel tracking tests (in measured rut depth in %) with LEAB, the reference hot mix StAB and a high modulus mix Kjellbase

Mix		LEAB	StAB	StAB	Kjellbase
Year		2009	2009	2003	2003
Number of load repetitions	1000	1.5 %	1.5 %	3.0 %	2.9 %
	3000	2.4 %	2.0 %	3.5 %	3.7 %
	10000	3.7 %	2.4 %	4.8 %	4.4 %
	20000	4.5 %	2.6 %	5.3 %	4.8 %
	30000	5.1 %	2.8 %	5.7 %	4.9 %

Based on the results of all the mechanical tests it can be concluded that the functional properties of the half warm mix LEAB are comparable to the equivalent hot mix StAB. The tests and test results were verified by several road authorities in the Netherlands and they came to the same conclusion. For this reason LEAB has been used in 2009 in about 20 different kind of projects, including a section of 1.2 km on RW2, one of the most heavily trafficked highways in the Netherlands.

6 THE ENVIRONMENTAL PROPERTIES OF LEAB

In the Netherlands, the government has implemented a project called Sustainable Purchasing. The aim of this project is to encourage government authorities to take environmental aspects into account when purchasing products for public use. In this way, government authorities (national and provincial governments, municipalities and water boards) aim to ensure that 100% of products are purchased in accordance with sustainability guidelines by 2015.

In cooperation with SenterNovem, which works for the Dutch Ministry of Economic Affairs in the area of sustainability and innovation, the independent research bureau INTRON (2009) carried out a study to estimate the environmental scores that can be assigned to LEAB. This study was carried out using the Dutch standard NEN 8006 (2004). In this standard, a Life Cycle Analysis (LCA) type of study is carried out for LEAB which is produced in a gas heated asphalt plant. Based on the results of this study, a so-called Environmental Relevant Product Information (MRPI) sheet can be made. This MRPI declaration is a reliable and accurate way to quantify the environmental aspects of building materials and construction products and can be very helpful in the communication between providers and clients of these products.

In the LCA-analysis the used calculation unity is the StAB, the hot mix variant of LEAB. In the study the winning of constituent materials (crushed aggregates, sands, filler, bitumen and reclaimed asphalt), the production of the mix, the purveying, the transport and the final discard of LEAB and StAB are taken into account. Also emissions into the air, water and soil are investigated where the gasses CO_2, CO, NO_x, SO_2 and C_xH_y are taken along. In Figure 4 one of the results of the LCA-analysis of LEAB is presented. In this figure the following items are mentioned: abiotic depletion, global warming, ozone layer depletion, human toxicity, aquatic ecotoxicity, terrestrial ecotoxicity, photochemical oxidation, acidification, eutrophycation, energy, hazardous waste and finally nonhazardous waste.

From figure 4 it is concluded that the production of LEAB has a substantial effect on the environmental profile of LEAB. Transport and recycling are less important.

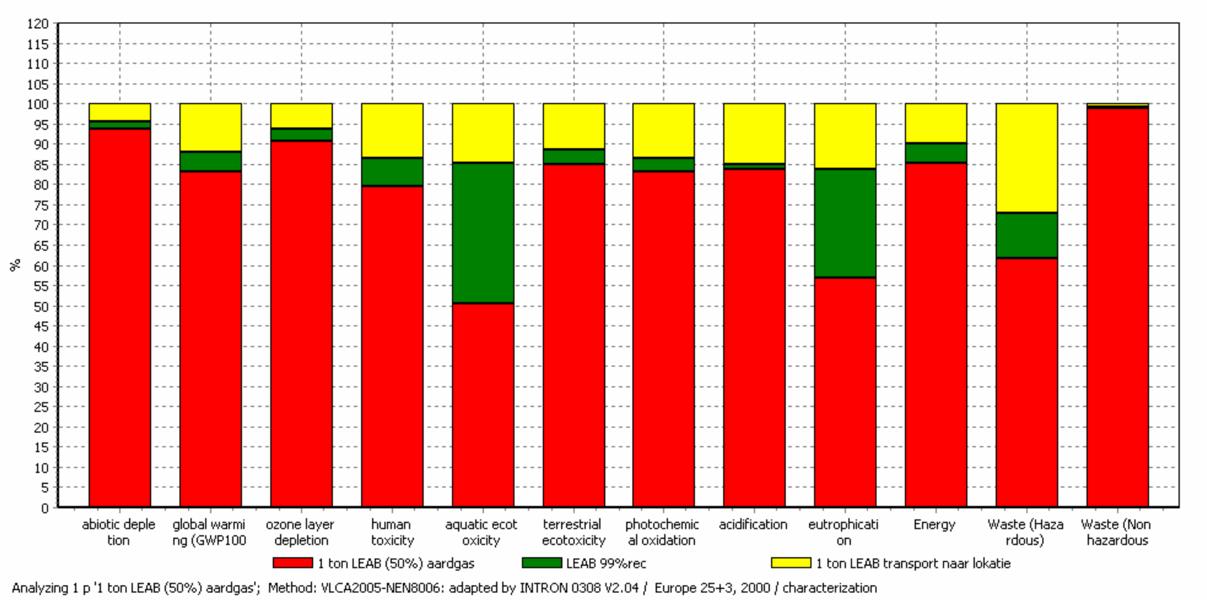


Figure 4: Relevant topics in the environmental profile for production, transport and discard of LEAB

Compared to the hot mix StAB, the environmental characteristics of LEAB are shown in figure 5.

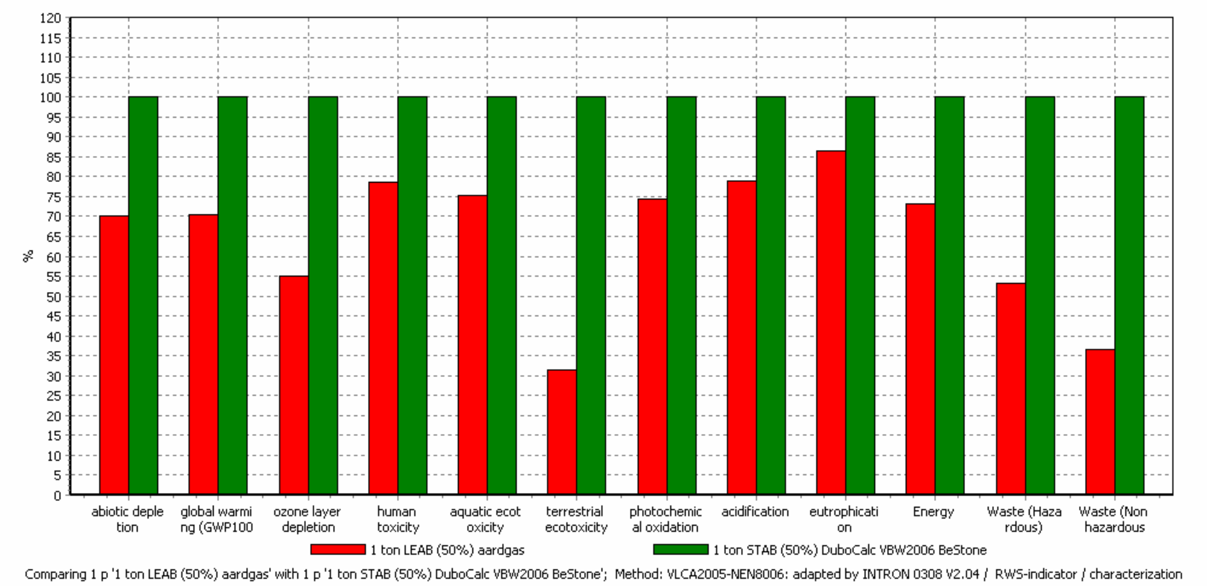


Figure 5: The environmental profile for production, transport and discard of LEAB and StAB in case of a natural gas heated asphalt plant and 50% RAP

In order to express the environmental properties of a material in one value, the Dutch Ministry of Transport (=RWS) has developed an indicator score. In this procedure effects are quantified in terms of money. In table 5 the results of the comparison between LEAB and

StAB are presented.

Table 5: The RWS-indicator for production, transport and discard of LEAB and StAB

Environmental effects	Unit	LEAB	StAB
Global warming	Euro/ton	$2.2 \cdot 10^{0}$	$3.1 \cdot 10^{0}$
Ozone layer depletion	Euro/ton	$3.1 \cdot 10^{-4}$	$5.6 \cdot 10^{-4}$
Human toxicity	Euro/ton	$9.6 \cdot 10^{-1}$	$1.2 \cdot 10^{0}$
Aquatic ecotoxicity	Euro/ton	$5.6 \cdot 10^{-2}$	$7.4 \cdot 10^{-2}$
Terrestrial ecotoxicity	Euro/ton	$3.1 \cdot 10^{-3}$	$9.9 \cdot 10^{-3}$
Photochemical oxidation	Euro/ton	$1.8 \cdot 10^{-2}$	$2.4 \cdot 10^{-2}$
Acidification	Euro/ton	$9.5 \cdot 10^{-1}$	$1.2 \cdot 10^{0}$
Eutrophycation	Euro/ton	$4.0 \cdot 10^{-1}$	$4.6 \cdot 10^{-1}$
Total	Euro/ton	$4.6 \cdot 10^{0}$	$6.1 \cdot 10^{0}$

Based on this environmental study it can be concluded that during the production of LEAB 25% less CO_2 is produced and 25 to 40% energy reduction can be achieved. Taking all environmental properties into account, LEAB is 25 to 35% less polluting than equivalent hot mix.

6 CONCLUSIONS AND RECOMMENDATIONS

Based on this study, the following conclusions can be drawn:

1. When choosing the right procedure, the right materials and right mixing tools, it is possible to develop a half warm mix with the same performance based specifications as a hot mix;
2. With the use of foamed bitumen, the production of the mix needs less energy as for hot mixes and the CO_2-emission is reduced substantially. For LEAB 25 to 40 % energy can be saved and at least 25% less CO_2-emissions can be accomplished. This implies that LEAB is at least 25% less polluting than the hot mix with the same mix composition;
3. The compaction of half warm mixes goes faster in comparison with hot mixes. The phenomenon behind this process is not yet understood;
4. Due to faster compaction at a lower temperature of the half warm mix, a new pavement can be used by the traffic right after finishing the compaction;
5. The use of RAP in half warm mixes is no problem. Up to 60% use of RAP is possible in the half warm mix;
6. In practice, the half warm mix can be used in all situations. However in rural situations with much hand labour, the use of a half warm mix is not advised;
7. Due to the lower temperature, the half warm mix does not stick to the trucks. This implies that the trucks stay clean during the total road job.
8. Because of the success of LEAB, there are plans to use the same foaming procedure to produce half warm mixes for binder and surface layers. Even the production of SMA and porous asphalt mixes are possible. One of the plans for 2010 is the realization of a test section with half warm porous asphalt.

REFERENCES

Csanyi L.H., 1957. *Foamed Asphalt in Bituminous Paving Mixes.* Highway Research Board

Bulletin, Volume 10, No. 160, pp. 108-122.

D'Angelo J., Harm E., Bartoszek J., Baumgardner G., Corrigan M., Cowsert J., Harman T., Jamshidi M., Jones W., Newcomb Dave, Prowell B., Sines R. and Yeaton B., February 2008. *Warm- Mix Asphalt: European Practice*, Report FHWA-PL-08-007.

INTRON, July 2009. *Life cycle analyses of LEAB produced in a gas heated asphalt plant.* Study, carried out by INTRON with report number A931600/R20085a/JMe/HVe.

Jenkins K.J., de Groot J., van de Ven M.F.C. and Molenaar A.A.A., 1999. *Half-warm Foamed Bitumen Treatment. A New Process.* Conference on Asphalt Pavements for South Africa, CAPSA, Victoria Falls, Zimbabwe.

Jenkins, K.J., 2000. *Mix Design Considerations for Cold and Half-Warm Bituminous Mixes with Emphasis on Foamed Bitumen.* PhD Dissertation, University of Stellenbosch, South Africa.

NEN, 2004. *Environmental data of building materials, building products and building elements for application in environmental product declarations - Assessment according to the Life Cycle Assessment (LCA) methodology*, Dutch Standardisation Institute NEN, Delft.

Sluer, 2004. *Development of performance based mix specifications for Kjellbase*, Paper Eurasphalt & Eurobitume Congress, Paper no. 320, Book II, pp. Viena.