LOW ENERGY ASPHALT MIXTURES FOR SUSTAINABLE AND DURABLE PAVEMENT SOLUTIONS

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Abstract

Internationally a growing health, safety and environmental awareness of the public is observed. In this context significant efforts are underway to develop advanced technologies to reduce the use of non-renewable fossil fuels, in order to reduce emissions and exposures. Also in the road industry the search for new solutions to produce more environmentally friendly is eminent. One of the most important developments into that direction is the introduction of asphalt mixtures that can be produced at lower temperatures. Lower temperatures means in general lower than 140ºC. In this paper national and international experience and research results will be discussed, Dutch trends will be supported with test results. Specifically the role of a Life Cycle Assessment will be given extra attention

1. INTRODUCTION

The goal of sustainable practices is to sustain economic prosperity and a high quality of life for everybody, and at the same time to protect the natural systems of planet earth. Sustainability includes economical, environmental, and social components. The road building industry in the Netherlands is using large quantities of bulk materials in asphalt concrete. Each year approximately 10 million tons of asphalt mixture is produced.

The Dutch Roads Agency (RWS) is following the sustainability approach in all its activities. In this context RWS is focusing on sustainable purchasing of all kind of services and products, also roads. RWS is officially stimulating the market since 2010 in sustainable practices at all levels. In this way RWS will have a strong impact via their purchasing policy on the development of a sustainable operating market in the civil sector. RWS has officially decided to work for all tenders on projects of reasonable size with sustainable purchasing from 2010 on. For this purpose a computer program called Dubocalc has been developed bij RWS (Schweitzer and Duijsens, 2010). Dubocalc is a computer program in which the costs of environmental effects can be quantified. It calculates with a live cycle analysis (LCA) all relevant environmental effects of the material- and energy consumption during the total life of a project. These environmental effects are converted into Euros with a so-called ECI (Environmental Cost Indicator). This approach really makes the process of sustainable purchasing much easier, because in a tender a solution can be given, which can be judged objectively by RWS and the candidate contractor on sustainability.

Dubocalc is an important tool to shape sustainable purchasing by the roads Agency. It uses harmonized methods to determine the environmental impact of Civil projects like road construction, bridges, etcetera. Essentially in this case is the data that is used as input in Dubocalc. In the Netherlands a national environmental database is used for civil works. Both the method and the database are managed by a foundation called “Bouwkwaliteit”.

The policy used by RWS stimulates significant efforts by the industry to develop advanced technologies to reduce the use of non-renewable fossil fuels, in order to reduce emissions and exposures. Also in the road industry the search for new solutions to produce more environmentally friendly is eminent. An important development into that direction is the introduction of asphalt mixtures that can be produced at lower temperatures. Lower temperatures means in general lower than 140°C.

The production of asphalt mixtures at lower temperatures (also called half-warm mixtures) can only be successful if the final product in the pavement structure can compete with the normally hot produced mixtures, but also when the environmental effect of additions etcetera is low enough to get good results in Dubocalc. As a consequence aspects like mechanical properties, quality, workability and durability of the product play an important role, which need to be included into the LCA.

At several places in the world extensive experience is available with the production and application of half-warm asphalt mixtures. Some national and international experience and research will be discussed. The Dutch trends will be described and supported with results in which the role of a Life Cycle Assessment will be shown for half warm mixtures.

2. LCA

As will be clear from the introduction a life cycle assessment is of huge importance in a sustainable approach. For example the use of recycled materials in pavement construction prescribes a good assessment of all the associated environmental impacts including energy consumption, emissions, leaching. In the Netherlands an LCA method is developed by the Dutch roads agency. The method will play an important role in the choice of the contractor during the bidding process. The hart of the LCA methodology is the inventory part. This is also the most reliable part of the LCA methodology.

Life cycle inventory (LCI) is based on standard LCI methodology and follows the internationally accepted standards presented in ISO 14040 series. In this way the LCA is a versatile tool to investigate the environmental aspects of a product, a process or an activity by identifying and quantifying energy and material flows for the system under investigation (Huang et al, 2009).

The use of a product or a process involves much more than just the production of the product or the use of the process. Every single industrial activity is actually a complex network of activities that involves many different parts of society. Therefore, the need for a system approach rather than a single object approach has become vital in environmental studies. It is not good enough to consider just a single step in the production. The entire system has to be considered. The LCA methodology has been developed in order to handle this system approach. An LCA covers the entire cycle from "Cradle to grave" including: raw material extraction, manufacturing, transport and distribution, use of the product, service and maintenance, recycling, final waste handling like incineration of landfill.

In a life cycle assessment a mathematical model of the system is designed. This model is a representation of the real system including various approximations and assumptions.

With the LCA methodology it is possible to study complex systems (including existing interactions between different parts of the system) to provide the best possible picture of the environmental impacts from an activity like the realization of a product.

It will be clear that for complete assessments it is necessary to input a lot of information. The same is valid when using lower temperature mixtures. The outcome of the assessment for lower temperature mixtures should be such that it is accepted by the whole road building industry.

In summary: LCA is based on the life cycle, it is an inventory of the exchange between the environment and economy (energy and materials input, emissions and waste output), it assumes that the function needed will be delivered.

For the LCA a range of impact categories can be used. This is required in the norms and contains categories like: abiotic depletion, global warming, ozone layer depletion, human toxicity, aquatic ecotoxicity, terrestrial ecotoxicity, photochemical oxidation, acidifaction, eutrophication, energy, waste (hazardous), waste (non-hazardous). These categories are also given from left to right in figures 1 and 2. Every impact category has reference limits, list of impacts and impact factors. The sum of the product of (all emissions)X (impact factors) gives the Global Warming Potential result.

For example: 1 kg CO_2 + 1 kg CH_4 = 25 kg CO_2 equivalent.

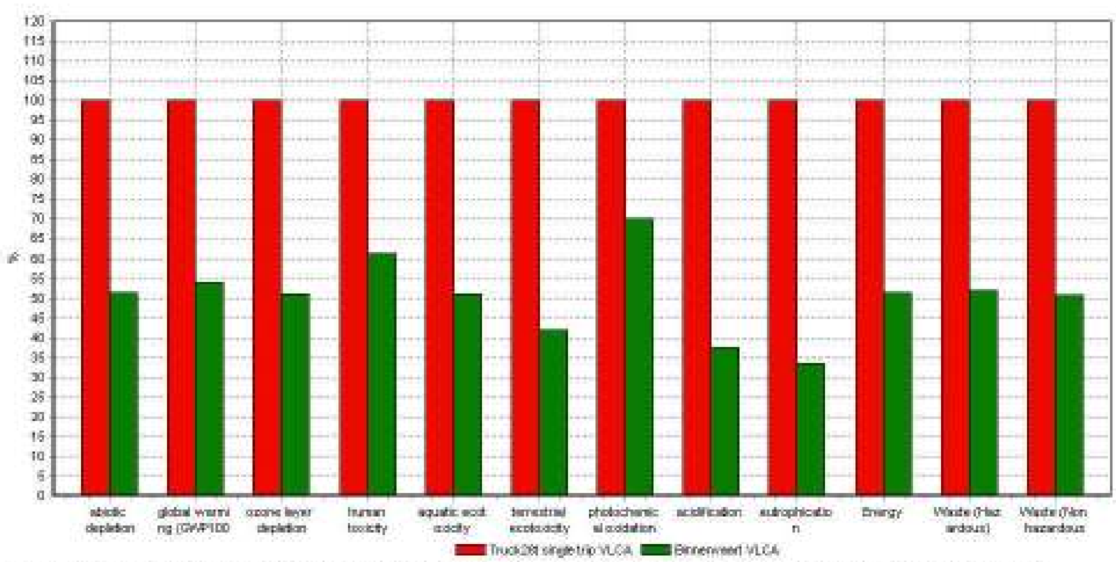

Figure 1. Example of the impact of the transport system: relative comparison of transport by a truck 0f 28 ton single trip (100%) versus transport by boat of aggregates (workshop Meijer, 2009). A clear description of the categories from left to right is given in the text above figure 1.

In figure 1 an example is given of the environmental profile based on an impact assessment of the transport of aggregates over a same distance for transport by a 28 tons truck over the road (100% for all categories as a reference) and the transport over water by boat. It is clear that the environmental profile of the boat is much better for all categories than the profile of the truck. In the Netherlands both possibilities can be used, so this is and important consideration for contractors if they want to score in an LCA.

3. LOWER TEMPERATURE MIXTURES

First the Dutch situation will be explained and then some techniques for half warm production will be discussed in this chapter.

3.1. The Dutch situation

Usual production temperatures at asphalt plants are ambiant temperature for cold mix plants (emulsion, foam mix plants) and temperatures above 160°C for hot mix plants. In the Netherlands the market is dominated by hot mix asphalt plants. More than 40 hot mix plants are well spread over the country, making hot mix asphalt a strong contender for a number of reasons like, relatively short transport distances, available subgrade, product ready after cooling (important in a rainy climate), and in general excellent performance of hot mixtures. Dependent on the binder used and mix type the production temperatures are mostly above 160°C with highest temperatures around 200°C for some mixtures with polymer modified bitumen. The high temperatures ensure complete drying of the mineral aggregates and low enough viscosity of the bitumen, resulting in excellent coating, workability and compaction. An important aspect for the Dutch asphalt industry is the high amount of reclaimed aggregate in the Netherlands. Most hot mix plants are of the batch plant type with a parallel drum, because in the Netherlands almost 100% of the milled off or broken asphalt is recycled in hot mix. The Dutch roads agency has stimulated maximum use of reclaimed asphalt in the eighties of the last century. As a consequence almost always percentages of 50% recycled asphalt (RA) are used thanks to the parallel drum system. In 2009 approximately 3 million tons of RA has been recycled in a total hot mix asphalt production of 10 million tons. The RA is heated in the parallel drum to a maximum temperature of 130°C to prevent the RA to stick together in large clumps, resulting in the requirement to overheat the virgin aggregate above

200°C at an RA percentage of 50% to get a final mixture temperature above 160°C. It is clear that both hot mix production with 100% virgin material and hot mix production with high RA (50%) addition as is usual in the Netherlands require quite a lot of energy.

As explained in the introduction the roads agency is forcing the asphalt industry to explore all possible ways to reduce the environmental impact of the asphalt production industry in all phases. With hot mix asphalt production reduction of the production temperature offers great possibilities in reducing consumption of fossil fuels, emissions of greenhouse gases, emissions of fumes for workers in the plant and at pavers, safety and working conditions for workers at the plant and work site, etcetera. From the point of environmental benefits the focus is on lower temperatures, less energy, less CO_2 and less odor. In the Netherlands this has to be combined with a maximum possible reuse of RA to reduce the use of non-renewable resources.

At the same time the roads agency pushes maximum availability of the road to traffic to prevent delays, resulting in a focus on high durability (long service life), high stability, high skid resistance, good noise reduction of surface layers, faster opening of the road after maintenance, less compaction effort, etcetera.

In a balanced approach all these aspects need to be taken into account and decrease in production-, transport-, laying- and compaction temperatures are no exception to this. Reducing production temperatures and good performance are in a sustainable approach linked to each other. So this means that for a successful introduction of lower temperature asphalt a number of aspects need to be ensured, like:

- Excellent mechanical performance immediately after laying
- During the service life: comfort, low noise production, good skid resistance
- Use of available equipment(hot mix plant, paver, compaction equipment)
- Economic solutions: recyclable, durable, low energy,
- Environmentally OK: reduction of heating, gases, emissions

3.2. Techniques to produce at lower temperatures

Techniques with (Doh et al, 2010) and without additives (Olart et al, 2009) are being proposed the last few years to lower the production temperature (. A distinction can be made between: decreasing the viscosity of the bitumen in the high temperature range, modification of the mixing sequence, creating a lubricating effect (example foaming), emulsification of the bitumen, etcetera.

In all cases the key is that the bitumen has to ensure a durable link between the aggregates to prevent stripping. This means that requirements are placed on adhesion and cohesion properties. This can be reached by allowing good wetting of the aggregate with bitumen through viscosity and surface properties of the bitumen and aggregate

Often used techniques at the moment are:

- Addition of waxes: waxes with a melting range between 80°C and 130°C are capable of lowering the viscosity of the binder in the high temperature range when they are completely molten. The wax modified binder shows at service temperatures (when the wax is crystallized) in the field higher stiffnes (viscosity) compared to normal bitumen. In case the crystallization temperature is above the high temperature service range, this can show benefits with regards rutting. At the low temperature side concern is about brittle behavior of the wax modified binder
- Zeolites: these aluminum silicates are capable of storing large amounts of water in their crystalline structure. Above 100°C they gradually release vapour which induces a controlled foaming effect in the bitumen. This improves the workability and compactability, resulting in lower production temperatures.
- Foamed bitumen is known to increase its volume and in this way creates a lubricating effect. Originally it was used for cold mix production, but (Jenkins, 2000) showed that at aggregate temperatures around 100°C excellent wetting could be obtained on practical all aggregate sizes.

Essential for application in the Netherlands of lower temperature mixtures is that it is possible to also use large quantities of RA (50%) in these mixtures with good performance. Only in that case lower temperature mixtures will be able to compete with hot produced mixtures with high amounts of RA, which is the largest production market in the Netherlands.

4. LCA OF LOWER TEMPERATURE MIXTURE COMPARED WITH HOT MIXTURE

First an example will be given of the outcome of a relative LCA comparison between a hot base course mixture and a lower temperature base course mixture. Then some information on mechanical properties determined on the lower temperature mixture will be discussed.

4.1 Results of LCA for a mixture produce at lower temperature

To show how the LCA system works an example will be given of a product that has gone through the process of LCA. In this case a special foamed bitumen product is used for the comparison, called LEAB (lower energy asphalt concrete). In fact this is a foamed bitumen mixture completely produced in a hot mix asphalt plant at approximately 100°C (van de Ven et al, 2007).

A relative comparison has been made with a hot asphalt mixture. Of course assumptions had to be made, because half-warm foamed bitumen mixtures are only in production for a few years now in the Netherlands. For an asphalt mixture the LCA has to cover the aspects as given in Table 1. Also the differences used in the LCA calculation between hot mix asphalt and LEAB are given in Table 1.

Table 1. Differences in the LCA between hot mix asphalt and LEAB

	Aspects	**Difference LEAB**
System	Fully recyclable Closed loop	Equivalent Equivalent
Materials	Fossil fuel based binder Mineral aggregates Mineral filler Engineered chemicals	Equivalent Equivalent Equivalent Not necessary
Energy	*Hot asphalt mixture* *Different fule types*	*Lower temperature* *Natural gas/bio-oil*
Emissions	*Different emission patterns* *Soot, VOC, PAH during application* Tar??	*Less and different* *Less* No
Logistics	Different distances	Equivalent
Durability	Maintenance and replacements	equivalent

As can be seen from Table 1 the large differences can be found in the energy and emissions (in italic). In Figure 2 the difference in environmental profile between a hot mixture and a lower temperature mixture is shown clearly. For all impact categories the reduction for the lower temperature mixture is considerable.

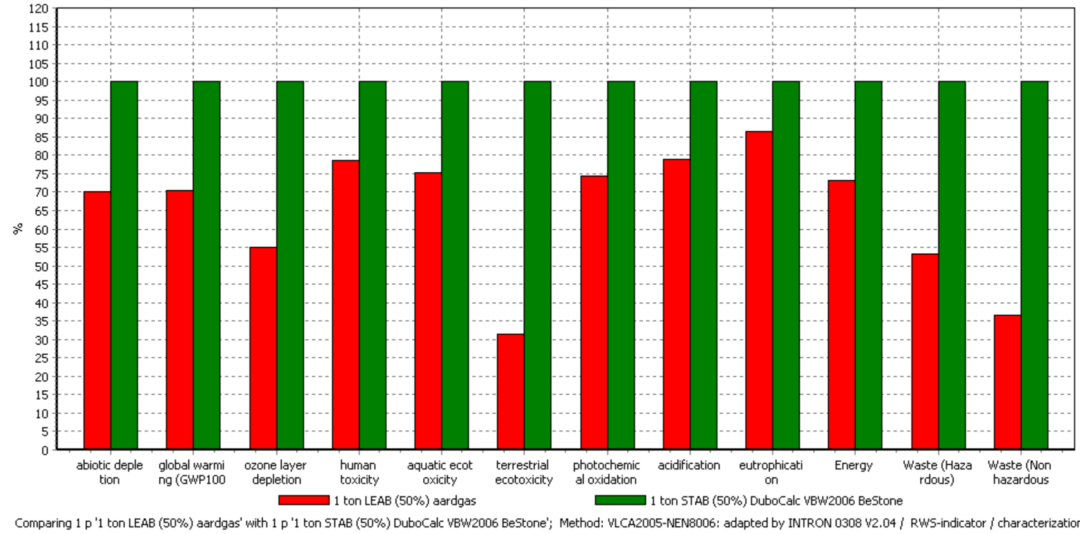

Figure 2. Environmental profile according to NEN 8006. 1 ton STAB hot mix (50%RA) compared to 1 ton LEAB (50% RA). The hot mixture (right columns) is for all categories placed at 100%. Categories from left to right are the same as in figure 1 and given in the text on page 3.

Table 2. Example of comparison between some impact categories between 1 ton hot mix asphalt (STAB) and 1 ton of LEAB with 30 % RA in both mixtures.

Impact category	Unit	STAB	Low temp. asphalt	STAB	Low Temp. asphalt
RWS-indicator	Euro's	5.6	4.8	100%	85%
Global warming	″	2.8	2.3	″	81%
Depletion ozone layer	″	0.00047	0.00039	″	84%
Human toxicity	″	1.2	1.0	″	87%
Aquatic ecotoxicity	″	0.047	0.039	″	83%
Terrestic ecotoxicity	″	0.0098	0.0061	″	62%
Summer smog	″	0.024	0.021	″	90%
Acidification	″	1.2	1.1	″	90%
eutrophication	″	0.33	0.29	;;	89%

In a LCA based calculation program like Dubocalc the environmental profile is converted into money (Euros). An example is given for a number of impact categories Table 2. The significance of these differences in money (Euros) is also given in Table 2. In Dubocalc these differences will be convert into an amount of money that has to be included in the bidding process. These differences can have considerable influence on the result of bidding processes for projects.

The influence of the categories global warming, human toxicity and acidification are the dominant ones in this comparison in Euros. The results demonstrate that it is very interesting to investigate the possibility of using new innovative ways to produce asphalt mixtures with an environmental profile that can make a difference in the choice of the roads agencies.

4.2 Mechanical properties

As has been made clear before, it is very important that a lower temperature mixture has not only a better environmental profile, but also the performance of the lower temperature asphalt mixture need to be sufficient to compete with hot asphalt mixture.
In the case of the base course mixtures compared in paragraph 4.2 the comparison is made based on the functional requirements used in the Netherlands for hot mix asphalt. Since 2010 in the Netherlands a system is in place with CE marking required based on the European norms and for these base course mixtures certain properties need to be satisfied. For base course mixtures the requirements are water sensitivity (retained indirect tensile strength ratio), stiffness (four point bending), fatigue (four point bending) and permanent deformation (triaxial test). The LEAB mixture has been tested for all these properties and satisfies all requirements. As example the results of the stiffness test and the fatigue test are given.

The stiffness and fatigue results are given in Table 3. These parameters can be used in a structural design to determine the thickness of the asphalt layers in the pavement structure.
In this way a clear comparison can be made between the contribution of the lower temperature mixture and the hot mixture to the structural capacity of the pavement layers. In figure 3 the fatigue line is given for the mixture of table 3. As can be seen quite some fatigue tests need to be done to be able to produce a decent fatigue line for which a good regression line can be drawn. The important point on the fatigue line to be reported is the strain level at which one million repetitions in the strain controlled fatigue test at 20°C test can be sustained.

Table 3. Stiffness and fatigue test results of LEAB at 20°C.

Stiffness		Fatigue	
Frequency [Hz]	Stiffness [MPa]	Parameter	value
0.1	1579	K_1	16.22
0.2	2146	K_2	-5.01
0.5	3156	R^2	0.93
1	4111	ε_6	110 µm/m
2	5246		
5	6982		
8	7954		
10	8410		
20	9956		
30	10943		

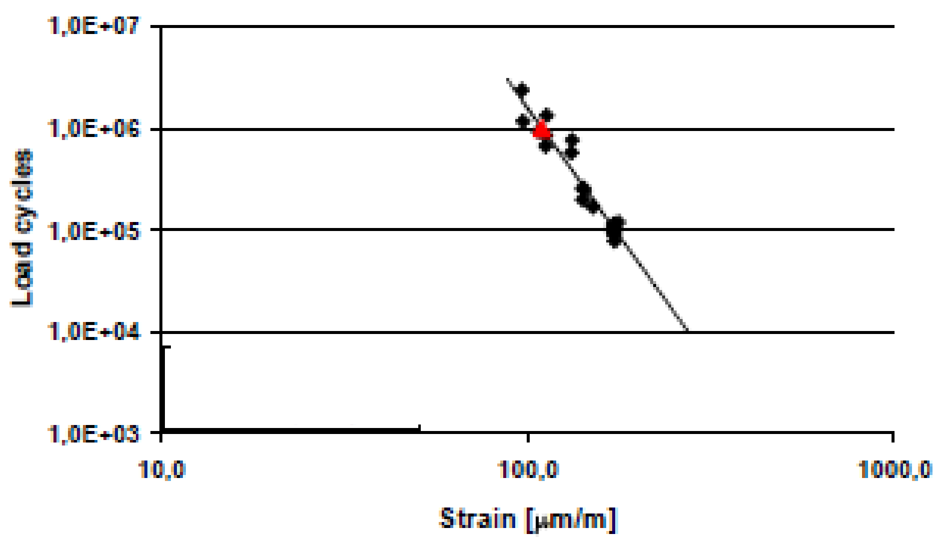

Figure 3. Example of the fatigue tests on LEAB for CE marking (see regression line in table 3). The one million repetitions on the regression line is the required strain value ε_6.

Finally it is interesting to compare the result of compaction tests in field trials between the hot mixture base course and the LEAB base course. The results are given in Figure 4 and 5.

It is remarkable to observe that the lower temperature mixture has a different order in the use of the compactors and that also the lower temperature mixture can be compacted easily to high densities after the same number of roller passes. This information confirms that a similar construction process can be used for the lower temperature mixture and that the same equipment can be used as for hot mix asphalt production.

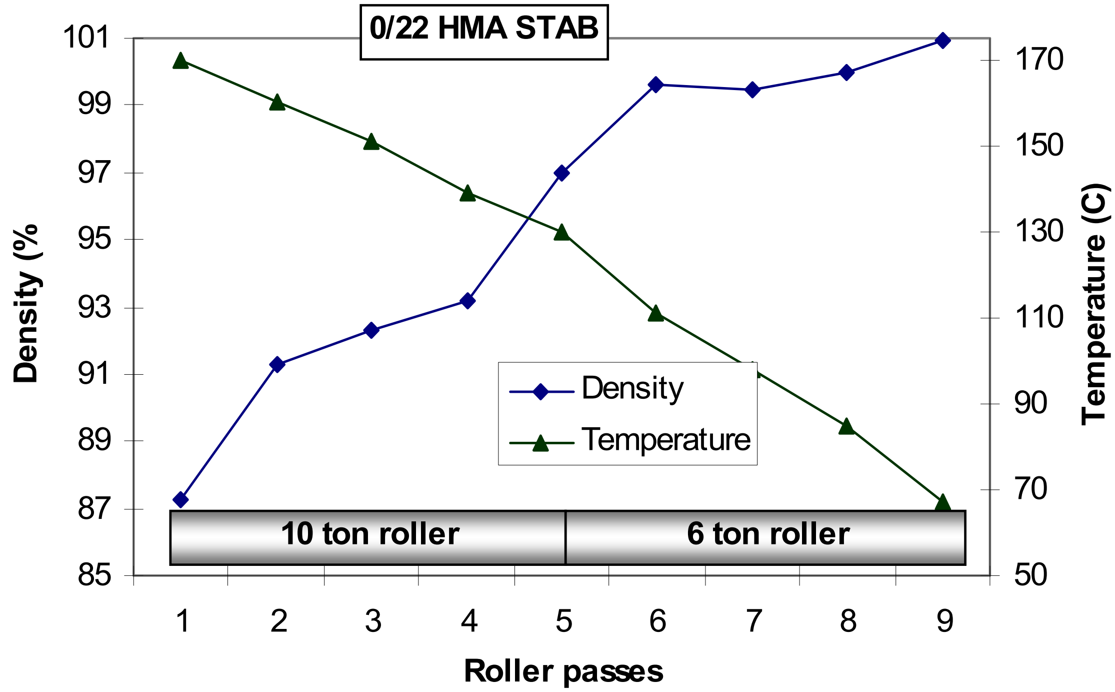

Figure 4. Compaction process for the hot base course mixture.

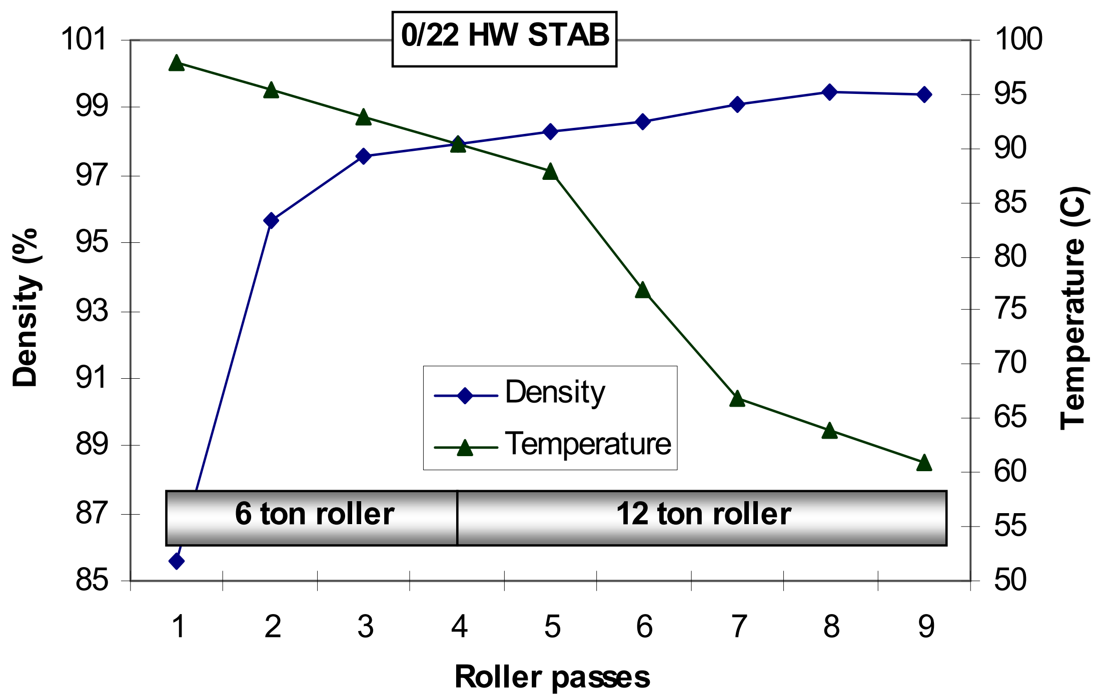

Figure 5. Compaction process for the LEAB base course mixture.

5. CONCLUSIONS

A sustainable approach requires new inputs from the asphalt industry.

An LCA will become an important tool in the coming years to show that sustainability is a key aspect in our industry.

Lower temperature asphalt production can make an important contribution to sustainable industry practices.

A relative LCA done with the Dubocalc program shows that the environmental profile of lower temperature asphalt is considerably better than for hot mix asphalt.

For the Netherlands the lower temperature asphalt mixtures probably need to include high percentages of reclaimed asphalt to be competitive with hot mixtures with 50% reclaimed asphalt.

Lower temperature asphalt mixtures need to satisfy the same performance properties as hot mixtures.

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KEY WORDS

Half-warm mixture, LCA, mechanical properties, field trials