Warm mix asphalt: an insight on durability and eco-friendliness

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ABSTRACT

Warm mix asphalt techniques have been around for a couple of years since the first field tests started across different European countries. Temperature reduction has potential to reduce pollutant emissions while achieving similar or equal performance to traditional hot mix, on the one hand, and health-damaging gases, on the other.

Several software suites have been published to address the environmental impact of a road or a given pavement. Among these are, for example, ECORCE (France), asPECT (United Kingdom) and CEREAL (European). Each one differs in the way they encompass all project stages and the pollutants they evaluate. Furthermore, they allow editing their database. Environmental benefits of warm mix were assessed using them. Furthermore, the quality of the built-in data was also assessed comparing the supplied data with real data of German asphalt plants.

In order to assess the field performance of warm mix, road condition data from two German test sites (A1 and A7 motorways) were evaluated. These sections have recently reached an age from which long-term conclusions can be inferred.

This study aims to compare the environmental and durability benefits of new asphalt technologies using real data and a direct comparison of the asPECT software's results.

Keywords: Embodied Carbon, Emissions, Energy saving, Warm Asphalt Mixture

1. INTRODUCTION

Warm mix asphalt techniques have been around for a couple of years since the first field tests started across different European countries. Temperature reduction has potential to reduce pollutant emissions while achieving similar or equal performance to traditional hot mix.
Several software suites have been published to address the environmental impact of a road or a given pavement. Among these are, ECORCE (France) and asPECT (United Kingdom). Each one differs in the way they encompass all project stages and the pollutants they evaluate. Furthermore, they allow editing their database. Environmental benefits of warm mix were assessed using asPECT.

Finally, in order to assess the field performance of warm mix, road condition data from two German test sites (A1 and A7 motorways) were evaluated. These sections have recently reached an age from which some long-term conclusions can be inferred.
This study aims to compare the environmental and durability benefits of new asphalt technologies using real data and a direct comparison of the software's results.

2. ANALYSIS OF WMA ENERGY CONSUMPTION AND SAVINGS

A simulation of the energy consumption of the asphalt layers of a standard 4-lane German motorway cross section was carried out with the programs "asPECT". "asPECT" is a software developed by British "Transportation Research Laboratory". Special focus was made on greenhouse gas emissions of asphalt mixtures.

The motorway is a motorway of the highest design class (in German: "Entwurfsklasse 1"), whose cross section is depicted in Figure 1:

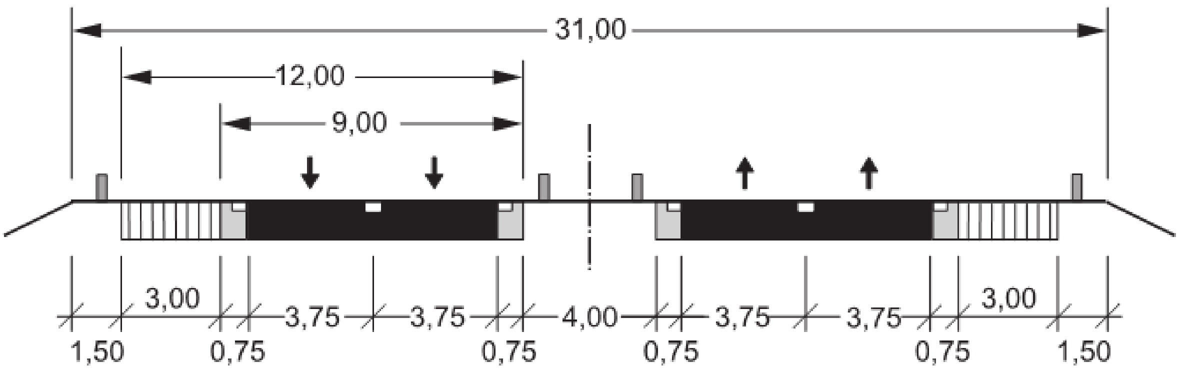


Figure 1: Motorway cross section. Source: [1]

The example pavement represents a "typical" German design choice for the highest load class "Bk 100" and is composed of the following layers:

- 4 cm SMA 11 wearing course
- 8 cm AC 22 binder course
- 22 cm AC 32 base course

Representatives of the German Asphalt Association (original German: "Deutscher Asphaltverband") were contacted to get a realistic energy consumption figure for German mixing plants and the fuel of choice. According to them, around 80 kWh of energy are required to produce 1 metric ton of asphalt. This figure includes plant start-up and shutdown and an aggregate moisture content of 3 – 4%.

An extensive literature research was performed to obtain a range of the mixing plant energy consumption. Literature values for Hot Mix Asphalt energy consumption range from the 270 MJ/t found in [2] to the 356 MJ/t obtained in [3] for Swiss asphalt plants. Unfortunately, no energy value was provided for common German Warm Mix Asphalt production practices. The values from the software "ECORCE" are provided by the software itself and are fixed values.

Table 1: Hot Mix Asphalt energy requirements

Mixture type	Thermal energy required [MJ/t]	Source and comments
Hot mix asphalt (5% moisture content)	270	[2]
Hot mix asphalt	270,979	Steady-state production. Average of asphalt plants in the Mid-Atlantic United States, both batch and drum [3]
Hot mix asphalt (gas fired)	280,39	ECORCE M software (France)
Hot mix asphalt	288	German Asphalt Association
Hot mix asphalt	288,979	End of year average. Average of asphalt plants in the Mid-Atlantic United States, both batch and drum [3]
Hot mix asphalt (fuel-oil)	303,82	ECORCE M software (France)
Hot mix asphalt	314,551	[4]
Hot mix asphalt	356 ±11	Average of six Swiss mixing plants [5]

Mixture type	Thermal energy required [MJ/t]	Source and comments
Warm Mix Asphalt (gas fired)	196,18	ECORCE M software (France)
Warm Mix Asphalt	206,580	Based on calculations from [3]
Warm Mix Asphalt (5% moisture content)	240	[2]
Warm Mix Asphalt (fuel-	266,48	ECORCE M software

oil)		(France)
Warm Mix Asphalt	266,52	[4],

2.1 asPECT calculations

The English software “asPECT” allows calculating the CO_2 emissions of a defined asphalt mixture. Depending on the input data, all phases between mixing and in-situ maintenance can be considered. “asPECT” contains an editable database of the CO_2 emissions of the constituents required to manufacture an asphalt mixture. The user must input the amount of energy or fuel required to heat the mixture.
Only one WMA technology (Fischer-Tropsch wax) was assessed. No reliable emissions data were found for other technologies (foaming, chemical additives) and, therefore, they were left out of the assessment.

For our example case, all phases up to the mixing were taken into account. A distance of 218 km, which was covered with a >17t truck, was assumed between the mixing plant and the refinery. For the aggregates, the distance was of 348 km. Transportation was not taken into account for the additive.

Six cases were calculated, three for a coal dust-fired plant and three for a fuel oil-fired plant. The energy savings were chosen according to the range found in the literature. Since energy savings not only depend on temperature reduction but also on the fuel type and the plant itself (energy losses) as well, it was chosen not to tie the energy savings to a specific temperature:

- Coal dust-fired hot mix asphalt plant
- Coal dust-fired warm mix asphalt plant with 11% energy savings and Fischer-Tropsch wax
- Coal dust-fired warm mix asphalt plant with 20% energy savings and Fischer-Tropsch wax
- Fuel oil-fired warm mix asphalt plant with 30% energy savings and Fischer-Tropsch wax

- Fuel oil-fired hot mix asphalt plant
- Fuel oil-fired warm mix asphalt plant with 11% energy savings and Fischer-Tropsch wax
- Fuel oil-fired warm mix asphalt plant with 20% energy savings and Fischer-Tropsch wax
- Fuel oil-fired warm mix asphalt plant with 30% energy savings and Fischer-Tropsch wax

The recipes for the asphalts were as follows (Table 3):

Table 3: asPECT asphalt recipes input

	PmB	**Aggregates**	**Fibres**	**Fischer-Tropsch wax**
Mixture type		**CO_2 emissions**	**CO_2 emissions**	**CO_2 emissions**
SMA 11 surf S	5,9% (5,8% in WMA)	93,8%	0,3%	0,1% (WMA only) *
AC 22 bin B S	4,2% (4,1% in WMA)	95,5%	Not used	0,1% (WMA only) *
AC 32 base T S	3,8% (3,7% in WMA)	96,2%	Not used	0,1% (WMA only) *

**: 0,1% is the minimum allowed amount that can be set in asPECT. Lower values are not accepted.*

The following tables (Tables 4 and 5) contain a summary of the calculation’s results:

Table 4: Summary of coal-fired plant CO_2 emissions

	Hot Mix Asphalt	**WMA 11% savings**	**WMA 20% savings**	**WMA 30% savings**
Mixture type	**CO_2 emissions**	**CO_2 emissions**	**CO_2 emissions**	**CO_2 emissions**
SMA 11 surf	94,97 kg CO_2eq/t	91,22 kg CO_2eq/t	88,59 kg	86,12 kg

S			CO_2eq/t	CO_2eq/t
AC 22 bin B S	90,32 kg CO_2eq/t	86,46 kg CO_2eq/t	83,83 kg CO_2eq/t	81,36 kg CO_2eq/t
AC 32 base T S	89,37 kg CO_2eq/t	85,47 kg CO_2eq/t	82,84 kg CO_2eq/t	80,37 kg CO_2eq/t

Table 5: Summary of fuel oil-fired plant CO_2 emissions

	Hot Mix Asphalt	**WMA 11% savings**	**WMA 20% savings**	**WMA 30% savings**
Mixture type	**CO_2 emissions**	**CO_2 emissions**	**CO_2 emissions**	**CO_2 emissions**
SMA 11 surf S	91,28 kg CO_2eq/t	93,84 kg CO_2eq/t	91,54 kg CO_2eq/t	88,99 kg CO_2eq/t
AC 22 bin B S	86,62 kg CO_2eq/t	89,19 kg CO_2eq/t	86,89 kg CO_2eq/t	84,33 kg CO_2eq/t
AC 32 base T S	85,68 kg CO_2eq/t	88,24 kg CO_2eq/t	85,94 kg CO_2eq/t	83,39 kg CO_2eq/t

It can be seen on the table that the benefits of Warm Mix Asphalt aren't the same for both types of fuels. This can be explained by the fact that the CO_2 emission savings of both fuels are different for the same amount of saved energy. While the usage of a warm mix Fischer-Tropsch additive brings immediate gains in a coal-fired plant, this isn't the case for the fuel-oil plant. Interestingly, the emissions of the Fischer-Tropsch additive offset the emission gains caused by the reduction of the energy consumption until a percentage of slightly over 20%. It must be noted that those conclusions do apply for Fischer-Tropsch wax-modified WMA only and different results may be expected when using other WMA technologies.

Since, at the moment, most German asphalt plants have shifted to coal dust, the usage of Warm Mix Additives could be of big interest for the German asphalt industry in order to improve their environmental record.

3. FIELD PERFORMANCE OF TEMPERATURE-REDUCED ASPHALTS IN GERMANY

3.1 Introduction

In order to evaluate the performance over time of a stretch of road built with temperature-reduced asphalt and the equivalence between classical hot mix and temperature reduced asphalts, permission to access the German National Road Condition Acquisition and Evaluation Database ("Zustandsdatenerfassung und -bewertung") was requested to the relevant authorities. The German National Road Condition Acquisition and Evaluation Database stores data from all German Federation-maintained roads since 1991 (Federal roads "Bundesstraßen" and Federal motorways "Bundesautobahnen"). Those are collected on a 4-year basis.

The following three parameters were selected to evaluate the durability of the mixtures:

- Mean rut depth on each test field, measured with a laser profilometer
- Cracking/material loss
- Overall unevenness (German: "Allgemeine Unebenheit", IRI counterpart): This method performs a spectral analysis of the road surface roughness to calculate an "overall unevenness index" based on the wavelengths of the road defects.

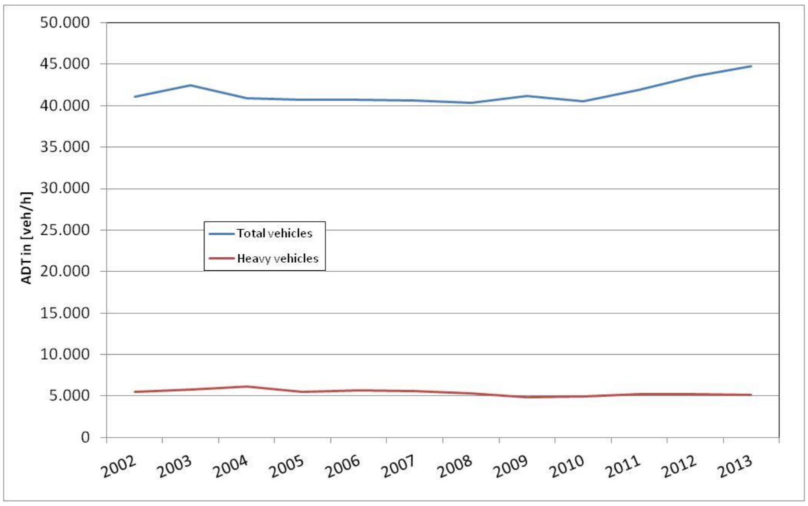
Finally, to prevent copyright issues, all additive's names and trademarks have been omitted from this paper.

3.2 A1 Test field, Germany

The first selected test field was built by the BASt, in collaboration with Straßen NRW (North Rhine-Westphalia State Road Authority), at the A1 motorway on October 2002. It is located at the Cologne-bound carriageway, near Euskirchen. Nowadays, this section links the mountainous region of the Eifel and southwestern North-

Rhine Westphalia with the Cologne-Bonn area until the unfinished “Eifel-Motorway”, to which it belongs, is completed.
Average daily traffic of the section, according to [2], amounted to 40.100 veh/24 h. Of those, 9,7% were heavy vehicles. As the data provided by the nearby Euskirchen/Bliesheim traffic counting station was found to be very similar to the real traffic on the test field, they were used to get an image of the traffic evolution over time [3]. Figure 1 depicts the ADT from the time of construction until the year with the last available data:

Figure 1: Traffic evolution at Euskirchen/Bliesheim, 2002-2013 Source: (Bundesanstalt für Straßenwesen, 2015)



Traffic intensity (Figure 1) has remained pretty constant at around 40.000 vehicles/24 h over the years, though a significant increase of ca. 5.000 light vehicles took place in 2013. On the other hand, a slight decreasing tendency can be appreciated on the heavy vehicles curve. However, values tended to hover around 5.000 heavy vehicles/24 h. When compared to the national average, the figures of the counting station are slightly lower than the national average of 47.600 vehicles/24 h and 7.090 heavy vehicles/24h [4].
The main purpose of the test field was to evaluate the emissions reduction of temperature-reduced mastic asphalt mixtures. Alongside the reference, 3 different additives were used. Furthermore, the performance of the section in the durability area was constantly monitored. Table shows the mixture composition built on the test field:

Table 6: Composition of the mixture used at the A1 test site

Mixture: MA 0/11 S (old German nomenclature: GA 0/11 S)

Basalt – coarse aggregate 8/11	22,0 M.-%
Basalt – coarse aggregate 5/8	14,0 M. -%
Moraine – coarse aggregate 2/5	15,0 M. -%
Basalt – crushed sand 0/2	16,0 M. -%
Natural sand	6,0 M. -%
Limestone filler	27,0 M. -%

Bitumen: Standard 20/30 (reference section), 20/30 with additives A1, A2 and A3
Data from two different years (2006 and 2010) were analyzed to get a better overview of the field’s evolution:

Figure 21: Mean rut depth, 2006 and 2010, A1 test field, Euskirchen

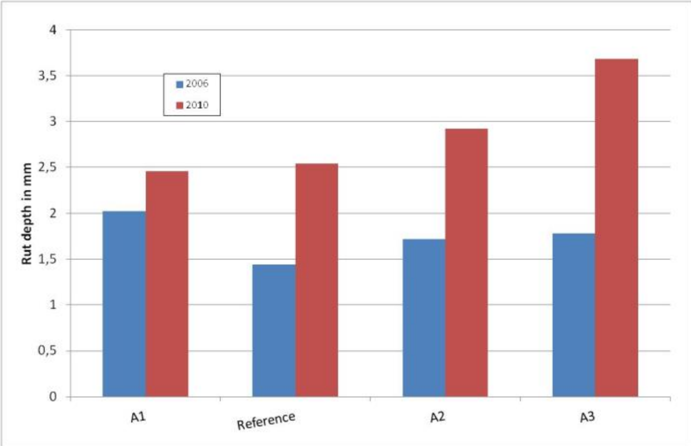
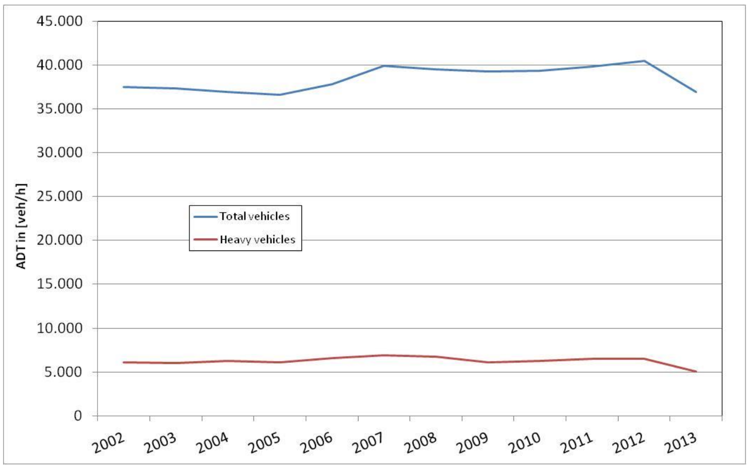


Figure 2 shows rut depth evolution for the years 2006 (four years after construction) and 2010 (eight years after construction). Although the reference mixture performed better than the WMA sections at the beginning, no significant difference was found over the years between all sections. The maximum measured rut difference was of 1,2 mm. No explanation was found for the fact that the section treated with the additive A1, after having been the worst performer of all test fields in 2006, obtained the best results on the long term.
Sudden temperature reductions during the paving process could have been the cause for the observed material loss on the reference section, which was severe enough to be considered as a road defect according to the German evaluation system. A1 and A3 sections also showed some cracking, albeit not so severe to reduce the section "overall condition" mark.

3.2. A7 Test field, Germany

An initiative was started during 2003 to encourage the German asphalt industry to participate in a warm mix test field campaign. Approval was given to build one of them on the A7 motorway between the Schwerin-Schuby and Owschlag exits. The location was chosen due to its high load class (SV) and due to its location on the motorway linking Denmark with the rest of Germany and the major port of Hamburg. An overview of the ADT at the nearby counting station Owschlag (no junctions lie between the test field and it) is depicted on Figure:

Figure 3: Traffic evolution at Owschlag, 2002-2013 Source: (Bundesanstalt für Straßenwesen, 2015)



It can be seen in Figure 3 that total traffic has decreased in 2013 from its 40.500 vehicles/24 h peak of recent years to 37.000 vehicles/24 h. After remaining constant for years, heavy vehicle's traffic intensity also fell to 5.000 vehicles/24 h.

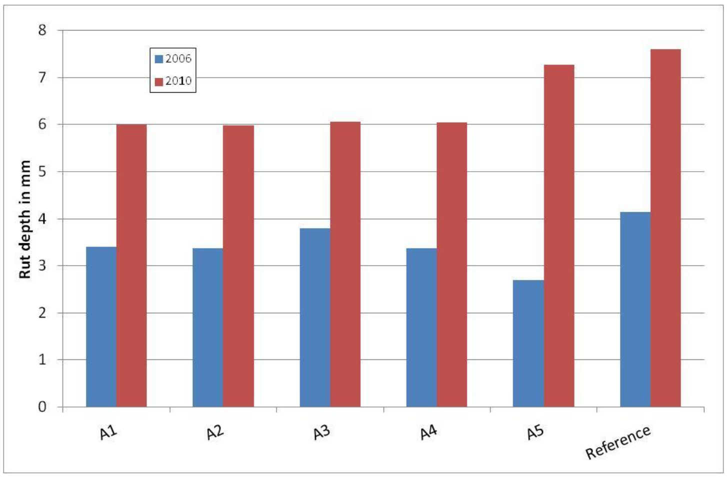
Five different test sections consisting of four different warm mix additives and a reference mixture, respectively, were paved on a 4,6 km long stretch of the Hamburg-bound carriageway. Both the 0/16 S asphalt binder course and the 0/11 stone mastic asphalt were built using the additives.

The paving of some sections proved challenging and led to compaction and smoothing difficulties, which led to rut depth values that exceeded the contract requirements. Since the problem affected all sections, meaningful results of rutting behavior can still be deduced from the data. In addition, several problems arose in the B1 and B2-modified mixtures during paving and were documented in the report that put into doubt their suitability for reduced temperature applications.

Figure 4 contains a summary of rut depth behavior over the years. In this case, the reference section was the worst performer of all monitored sections both at an early stage and later in time. On the other hand, it can be deduced from the diagram that the warm mix sections tended to show a similar behavior over time despite the initial differences between their rut depths. The maximum calculated rut depth difference was found to be 1,6 mm.

Almost all sections were free of cracks or other defects on the right lane. Some cracks were present on the B3 section and the reference sections on a reduced length. These were not significant enough to cause an overall rating reduction.

Figure 4: Mean rut depth on the right lane, 2006 and 2010, A7 test field, Schwerin-Schuby



3. CONCLUSIONS

The following conclusions can be drawn from the research:

- Fischer-Tropsch-based Warm Mix Additives have the potential to reduce energy savings on coal-fired asphalt plants. However, the emission gains are offset by the additive impact on fuel-oil fired plants. This is due to the differences in CO_2 emission gains between both fuels.
- The use of Warm Mix Additives could be of interest for the German asphalt industry, which employs mainly coal dust in their mixing plants, because of the reduction in CO_2 emissions.
- Field performance of temperature-reduced mastic asphalt and SMA was found to be not significantly different than that of the classical mixtures. Rut depth and cracking was very similar to that the reference mixture.
- As short-term rutting behavior, compared to the reference mixture, of the temperature-reduced asphalt was different in the A7 and the A1 test fields, no meaningful conclusion can be drawn on this topic. As with all test fields, differences during paving, compaction or uncategorized external influences on the test section can lead to unexpected behavior. Therefore, more field experience with WMA should be collected before claiming its complete equivalence to Hot Mix Asphalt.
- The temperature reduction must be closely monitored when paving with Warm Mix Asphalt additives due to potential paving difficulties. This was observed at the A7 test field.

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Comentarios del reviewer 135

Table 1 and 2: Title above tables! Are the values for ASPECT and ECORCE fixed or calculated?
Figure 1: Why example of motorway here? The calculation is done in 2.1!
Section 2.1: Check cases in list (coal/fuel fired; 11, 20, 30 % savings). Is there an ECORCE calculation?
Table 3: Delete CO2-emissions from second line. Why fibers in a AC 22 B S?
References: Check font size

Comentarios del reviewer 500

Abstract
- 1st Para - delete the following ", on the one hand, and health -damaging gasses, on the other" - redundant.
- 2nd Para - Delete references to PaLATE and CEREAL as they were not used.

1. Introduction
- 1st Para - see 1st Para above.
- 1st Para - "since it was unavailable to obtain a copy of PaLATE and CEREAL is are currently unavailable to the public."

2.1 asPECT calculations
- clarify that only one technology was chosen for analysis. May not be indicative of all WMA technologies.
- what is meant by 11%, 20% and 30% energy savingsa? If this is related to a lower temperature, please state the temperature of the reference mix (HMA) as well as the production temperatures for the WMA to tie the temperature to the energy savings.
- in conclusions after Table 5, clarify again that this applies only to Fischer-Tropsch wax and different results should be expected for other WMA technologies.
- it is interesting to note that all German asphalt plants have switched to coal dust even though that increases the CO2e by 4%
- 2nd last para describing Figure 2 – the rutting observation is interesting as it has been suggested that WMA may rut more in early years because the mix has not been heated as hot. This is not observed in this section.
- last para – what is meant by “Sudden temperature reductions during the paving process”? does this mean that there was a sudden onset of cold weather during paving operations that resulted in low compaction in the field and thus resulted in ravelling in service? Or is this a reference to the actual production of the warm mix?

3.2 A7 Test field, Germany
- 4th para – replace “temperature-sank” with “reduced temperature”

Figure 21 (should be Figure 2)
- Labels on axes and data labels should be enlarged for clarity
Figures 3 and 4
- Labels on axes and data labels should be enlarged for clarity