Reduced emissions of warm mix asphalt during construction

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ABSTRACT

Warm mix asphalt (WMA) is produced at lower temperature and hence its production in the asphalt plant is favourable in terms of energy consumption and CO_2 emission. As a side effect, it is expected that the emissions during pavement construction are reduced too, which is highly relevant for work place hygiene and for the environment.

In a field trial five pavement sections were constructed with different warm-mix asphalt types and one hot mix asphalt used as a reference. During construction six road workers were equipped with personnel samplers to determine their exposure to pollutants relevant for occupational health. Particular attention was paid to the total particulate matter (TPM) and the polycyclic aromatic hydrocarbons (PAH). In addition, emissions of TPM, PAH, and other organic pollutants (volatile organic compounds (TVOC), aldehydes and isocyanates) were sampled on paver and rolling compactor. To evaluate the total emissions from the road construction, an integrative pollutant sample was collected downwind of the construction site. Mass emissions were estimated using a tracer gas technique (SF_6, SF_5CF_3) with constant dosing at known source strength. In parallel a series of laboratory experiments were carried out on the same material to elucidate differences in the emission behaviour between the warm mix asphalt types under more controlled conditions.

The laboratory experiments indicated a 90 % reduction of TPM and 50-70 % lower TVOC values by the use of WMAs in comparison to hot mix asphalt. Emissions of pollutants during road construction, however, were low for all asphalt types, mostly below the detection limits and the maximum allowable concentrations. This demonstrates the benefit of the temperature reduction during road construction for occupational health and the environment.

Keywords: Warm mix asphalt (WMA), emissions during construction, occupational health, PAH, TVOC

1 INTRODUCTION

Reduction of energy consumption and CO_2 emission is an important issue in asphalt production. Hot mix asphalt (HMA) is still the actual standard in many countries although new technologies are available to produce asphalt at lower temperature [1]. Warm mix asphalt (WMA) is typically produced at temperatures in the range of 20 to 40ºC lower than traditional hot mix asphalt. Different techniques to produce warm mix asphalt are available, e.g. addition of wax, zeolites, chemical additives and foam bitumen, and it is difficult to weigh the pros and cons of the different WMA types. Therefore, objective criteria are required to support decision-making by road authorities and other customers, including durability, ecological balance, occupational health, for specific pavement types.

Temperature reduction is an efficient way to reduce emission of pollutants during road construction as has been demonstrated in previous work [2]. However, environmental agencies are reserved towards WMA due to the lack of data and the addition of chemical additives of unknown composition for some WMA types, which could be released during road construction resulting in an occupational hazard for road workers [3]. Moreover, warm mix techniques are often used in conjunction with recycled asphalt pavement material (RAP). RAP is sometimes heavily contaminated with tar, known to contain large amounts of toxic polycyclic aromatic hydrocarbons (PAH), which are released to some extent during construction. Measurements taken during actual road construction are required to determine the exposure relevant to occupational health, i.e. the harmful substances directly inhaled by the workers. Few studies on emission measurements during road construction were conducted so far due to the complex sampling and analytical technique [4-6] in particular for WMA [7]. In this project, emission and occupational health measurements were taken during a field trial in Switzerland, where five pavement sections were constructed sequentially with four warm asphalt mixture types and one HMA reference material [8].

2 EXPERIMENTAL

On a trial site four different types of WMA were constructed as binder courses (AC B 16 S [9]) together with hot mix asphalt used as a reference. Each test field was 170 m long and was constructed on the same day with two pavers working in parallel. All mixes were identical in terms of binder content, binder viscosity (penetration value) and aggregate size distribution. Three different types of warm mix technologies have been applied including foam bitumen, zeolite and a chemical additive (Table 1). Two variations of foam asphalt were produced, one with 50 % RAP (WFR) and one without recycling material (WF).

First, a conventional hot mix asphalt was placed as a reference at a temperature between 153 and 164°C. Next, two warm-mix asphalts were laid at temperatures between 130 and 140°C. The first contained a surface-active chemical additive for reducing the friction in the mixture (WC), the second a hydrated zeolite (WZ), causing the water adsorbed in it to form a temporary bituminous foam. Finally, two road pavements were produced using foamed asphalt at between 112 and 140°C.

TABLE 1 Temperatures for WMA and HMA construction

Material	Warm mix technology	Production temperature [°C]	Construction temperature [°C]
HMA (reference)	-	165	145
WC	Chemical additive	135	123
WZ	Zeolite	135	128
WF	Foam bitumen	115	106
WFR	Foam bitumen + 50% RAP	115	107

2.1 Emission measurements

Six road workers with different tasks (2 paver drivers, 1 roller driver, 3 workers with universal tasks) were equipped with personal samplers to measure the occupational health exposure. Stationary Additional sampling devices were installed on two pavers with air sampling at roof height of the pavers (Figure 1). Further sampling was conducted at the lee side of the construction site in order to determine the total emissions of the pavement activities. Dilution of pollutants was considered using a tracer gas technique with constant tracer gas dosing (SF_6 or SF_5CF_3) at the main emission sources (both paver and one roller compacter). Total emissions of a target substance were calculated as the ratio of target and tracer gas multiplied with the mass emissions of the tracer gas. A combination of glass fibre filters and adsorption tubes filled with different resin types were used to collect the pollutants at the three stationary measurement points and in the personal sampler. Total particulate matter (TPM), total volatile organic compounds (TVOC) and the 16 EPA-PAHs were collected on membrane filters and/or adsorption tubes. Separate samples were collected for each pavement section and afterwards analysed in the laboratory gravimetrically (TPM) or by GC-MS (TVOC, PAH) [8].

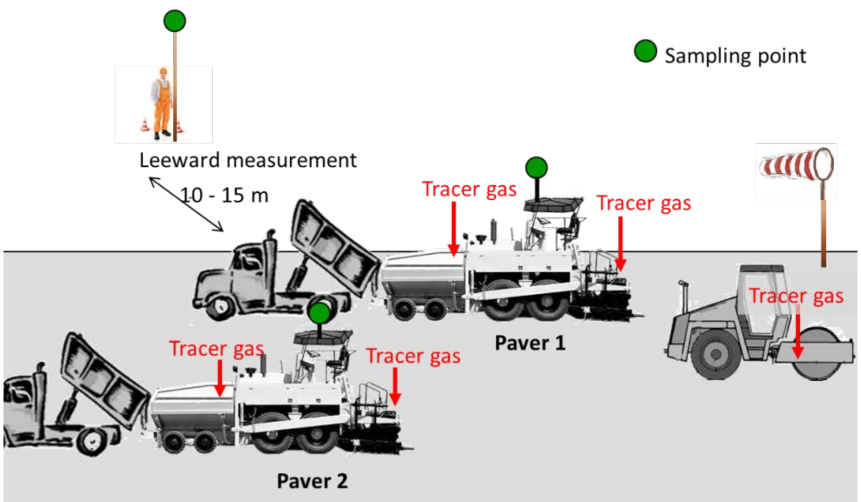

FIGURE 1 Schematic of the emission measurements

FIGURE 2 Laboratory measurements

Since the comparability of emission measurements from different surface materials under defined construction conditions based on field sampling is limited due to the differing topographical and meteorological conditions, results were complemented by laboratory measurements. This also enabled a higher level of sensitivity (lower detection limit) for the analysis of pollutants, which was limited at the real construction site due to the short installation sections. In the laboratory, the mixture samples taken from the construction site were pre-heated in an oven to approx. 90°C and subsequently mixed in a closed 150 kg laboratory mixer for 120 minutes at the respective construction temperatures (Figure 2). Sampling for TPM, TVOC and EPA-PAHs was conducted identically to the field measurements.

3 RESULTS AND DISCUSSION

Emissions of pollutants during road construction were low for all WMA types including the reference HMA. The length of each test field of 170 m, equivalent to 40 minutes of construction time, turned out to be too short for the measurement of the low pollution concentrations. Consequently, not enough solid particles were collected on the filters for gravimetric analysis and most of the measured data were below the detection limits. Total emissions for the road-building were evaluated based on tracer gas concentrations at the "leeward measurement site" and the volume of tracer gas supplied.

3.1 Total particulate matter (TPM)

In the field measurements, all TPM results including HMA were below detection limit. Therefore, the particulate emissions from all mixtures including hot mix asphalt were significantly below the Swiss regulated maximum workplace concentration (MAK) of 10 mg/m^3 for bitumen (fumes and aerosols [10]).

Laboratory measurements indicated that emissions of TPM are essentially influenced by the temperature of the mixture. TPM emissions of HMA (5.2 mg/m^3) were around ten times higher compared to warm mix asphalt, which lay close to the detection limits of 0.3 mg/m^3.

3.2 Total volatile organic compounds (TVOC)

In the laboratory, emissions of TVOC displayed a similar emission profile for all WMA types and no pollutants or derivatives produced by chemical additives were detected. As expected, the proportion of higher boiling point hydrocarbons n-octane to n-eicosane within total TVOC emissions was dominant, at 80% to 90%. The concentrations of individual substances relevant with respect to toxicity (e.g. benzene, toluene, cyclo-hexanone, benzaldehyde) were at least two times lower than the prevailing MAK values.

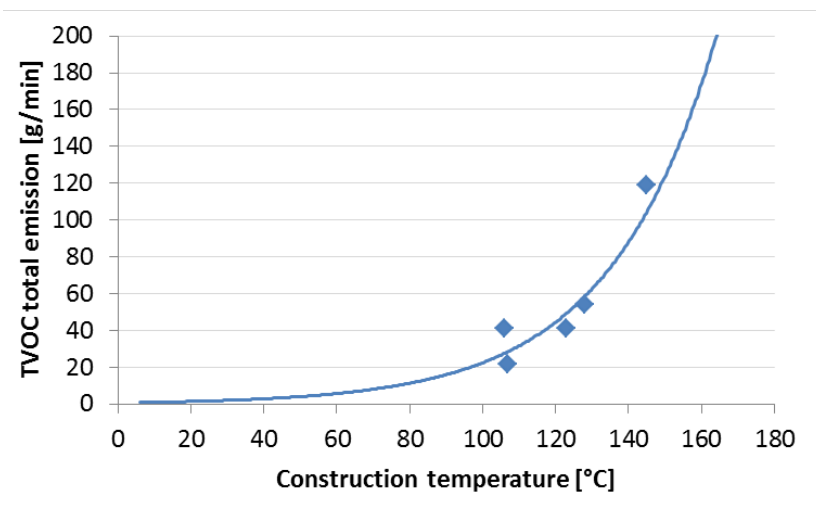

FIGURE 3 Correlation between construction temperature and TVOC total emission

In the field measurements no correlation to the construction temperature was found and the measured concentrations were 100 to 1000 times lower than under laboratory conditions. This was attributed to differing wind situations and the fast depletion of these volatile compounds. Using the information of the tracer gas measurements, it was possible to calculate the TVOC total emission, which showed a clear correlation with the construction temperature (Figure 3). In the laboratory the total amount of TVOC was similar for HMA, WC and WZ, but 50% lower for the two foam asphalt types (Table 2). However, in the field measurements the results of the stationary sampling points on the pavers were erratic and impossible to interpret.

TABLE 2 Concentration of TVOC emissions in μg/m^3 and total emission in g/min

Material	Laboratory	Paver 1	Paver 2	Leeward measurement	Total emission
HMA	57800	700	39	3010	119
WC	57000	369	36	1380	54
WZ	47400	1050	386	837	41
WF	16800	1680	896	1570	41
WFR	23800	577	596	1340	22

3.3 Polycyclic aromatic hydrocarbons (PAH)

The very low PAH release (Table 3) was apparently caused by a very low PAH content of the respective binders in the bituminous material. This was anticipated for the majority of the mixture types, since they do not contain any recycled material. However, it was surprising for mixture WFR with 50% RAP addition. But analysis of the applied RAP showed that it's PAH content of 25 ppm was rather low for Switzerland, where often RAP contents of 250 ppm and more are measured, due to the use of tar as a bitumen substitute in earlier time. Similarly, benzo[a]pyrene, frequently used as a lead substance for toxicity, was low as well and within detection limits.

In contrast to TPM and TVOC, PAH emissions were not affected in the same way by the temperature. Both in the laboratory and in the field, HMA didn't produce higher PAH emissions than warm mix asphalt except for WFR, which showed higher PAH-concentrations. However, the measured values were close to the detection limit and therefore conclusions should be made with reservations.

TABLE 3 Concentration of PAH*-emission in µg/m^3 during construction and in the laboratory

Material	Laboratory	Paver 1	Paver 2	Lee-measurement	Personal sampler 1-4
HMA	13	bdl	36	31	bdl -34
WC	12	bdl	bdl	bdl	bdl
WZ	14	bdl	bdl	bdl	bdl -35
WF	11	53	34	bdl	bdl
WFR	22	49	46	bdl	bdl -35

bdl: below detection limits of 31 µg/m^3; *16 PAH according the list of the US Environmental Protection Agency EPA

4 CONCLUSIONS

In summary, it can be concluded that the emissions of pollutants during construction of warm-mix asphalt were low, independent of the asphalt material, and were often below the detection limits of the applied measurement technique. This can be partly attributed to the short test fields and consequently short sampling time and small sample gas volumes. Emissions of particles TPM, PAHs in the field measurements lay within or below the respective detection limits. TVOC concentrations were equivalent to indoor air. This is not surprising, since pollutant emissions were also low in the laboratory experiments. Additionally, under realistic road building conditions pollutant concentrations are significantly lowered by dilution with ambient air.

Laboratory experiments demonstrate that reduction of construction temperature is an efficient measure to reduce pollutant emissions. TPM concentrations of warm mix asphalt are reduced by a factor of 10 and total TVOC emissions are 2 – 5 times lower with regard to HMA. Surprisingly, PAH emissions were not affected by temperature, but were all below or close to the detection limit. Concerning the different WMA types no conclusive difference was observed in terms of harmful emissions.

5 ACKNOLEDGEMENTS

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