Influence of pavement properties on PM_{10} emissions

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Background

Pavement wear is an important source for inhalable particles (PM_{10}) in ambient air. The source strength depends on pavement properties, climate and on traffic characteristics (e. g. Boulter et al. 2006). In Scandinavia, emissions of pavement wear PM_{10} are especially pronounced during winter and spring, when studded tires are used (e. g. Gustafsson et al., 2009). In many traffic intense city streets, the EU limit value for PM_{10} is exceeded which calls for action to reduce emissions. Since 2009, local authorities in Sweden have been empowered to prohibit traffic with studded tyres in certain streets/areas, and in Scandinavia both local authorities and the Transport Administration have run information campaigns on the health effects of particulates and on the harmful effects of studded tyres.

Another abatement possibility is adjusting road pavements, the actual particle source. In Sweden, road pavements have been adapted to withstand studded tyres, which means that at present aggregate-rich and coarse pavements with abrasion resistant aggregates are used on most of the heavily trafficked roads and streets. Nonetheless, more than 100,000 tons of road pavement material is abraded from national roads every year. Most of this is not PM_{10}, but much coarser material that ends up in the soil and in the water in the road environment, but a few per cents are PM_{10} and their contribution to ambient PM_{10} is important.

This work summarizes findings from 11 recent (2005-2011) research projects at VTI SLB-analys and ITM concerning how pavement properties affect PM_{10} emissions.

Methods

In laboratory, the VTI road simulator has been used with different pavements (Figure 1). The simulator consists of a circular track of 16 m diameter that can be surfaced with any pavement. The machine rotates about a central vertical axis equipped with four wheel axles driven by electric motors. During a test, the wheels are lowered down to the track at the desired axle weight, and the wheels cause the machine to rotate. Speed can be varied continuously up to 70km/h. The simulator is within a hall in which temperature and humidity can be controlled. Particle emission and properties are measured using TEOM (RP 1400a), DustTrak (TSI model 8529), APS (TSI model 3321) and SMPS (TSI) as well as particle sampling with cascade impactor and low volume samplers.

In the field, both stationary measurements and an instrumented van (EMMA) have been used (Figure 1). Stationary measurements included NOx and PM measurements at a test site compared to a reference site. The NOx concentrations were used as an indicator of exhaust emissions and in order to normalise the dilution of emissions with reference to differences in meteorology and topography. Measurements were also made of wind speed, wind direction, vertical and horizontal turbulence, temperature and relative humidity. The difference in PM_{10} concentration in relation to NOx (indicator for particles from vehicle exhausts) with reference to meteorology is a measure of the difference in particle generation by the pavements. The instrumented van EMMA is fitted with instruments for the measurement of particle concentrations and with batteries and other equipment (Hussein et al, 2007). It measures the particle emission from the road surface and particle size distributions using measurements behind both front wheels (GRIMM Technologies model 1.109 and DustTrak TSI model 8529).

In both laboratory and field tests, parameters important for total wear of pavements have been varied, including pavement construction, maximum stone size (Dmax) and Nordic ball mill value (NBM), the latter being a measure for wear resistance of rocks.

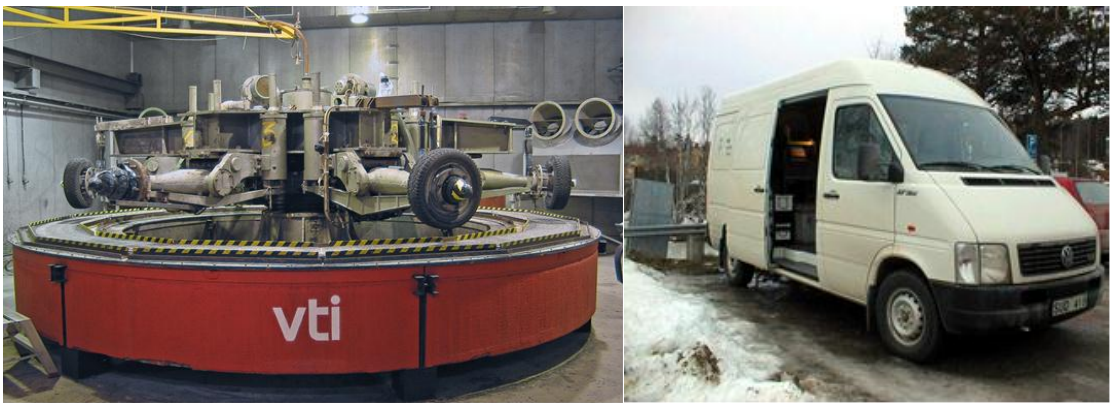

Figure 1: VTI road simulator and EMMA instrumented van.

Results

Size distribution measurements reveal that road wear dust within PM_{10} (< 10 µm aerodynamic diameter) is mainly above 1 µm (Figure 2) but that a substantial fraction is fine PM, i. e. PM2.5 (below 2.5 µm). The elemental composition reveals a dominance of rock minerals containing silica, aluminium, calcium, potassium and iron. The contributions from bitumen (binder) and tyres are small within PM_{10} as studded tyres are used.

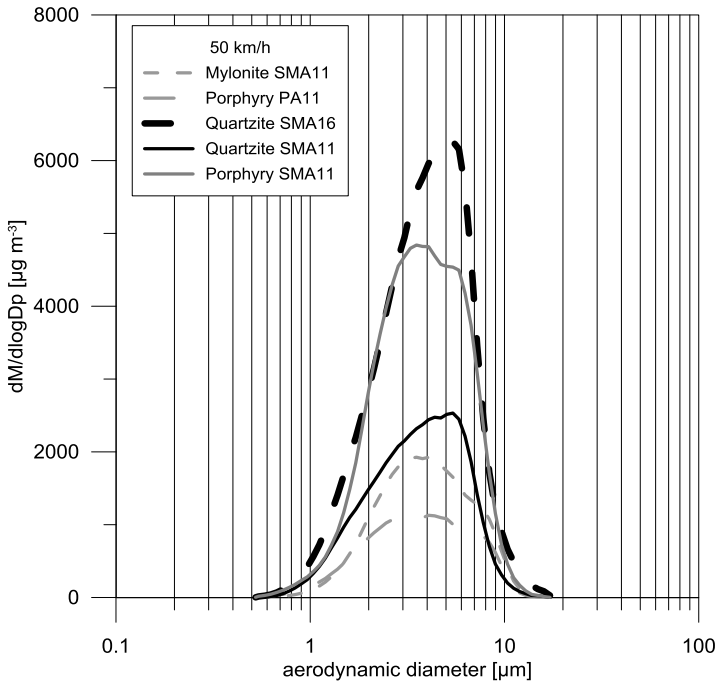

Figure 2: PM_{10} mass size distribution for five different pavements studied in the VTI road simulator.

Results from both simulator and field tests show that larger maximum stone size and lower Nordic ball mill value (Figure 3) of the rocks used will decrease the PM_{10} emissions from standard asphalt pavements.

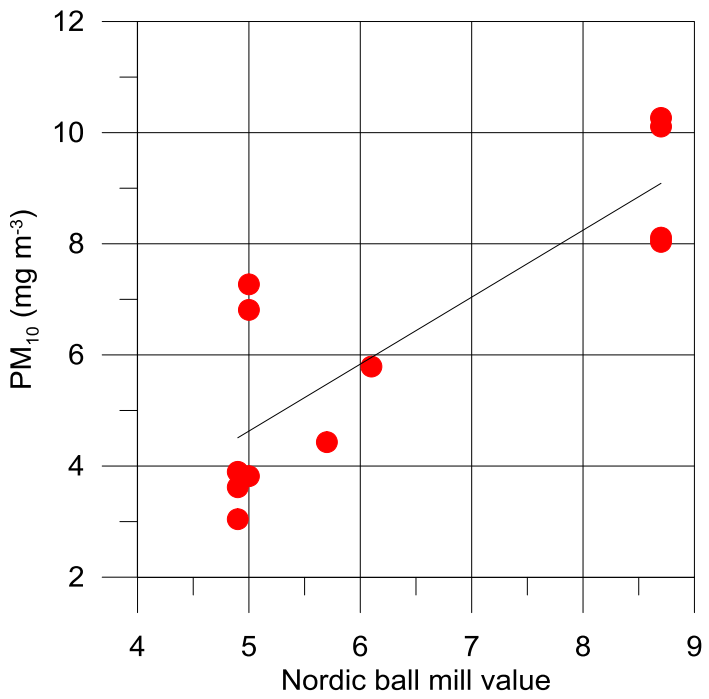

Figure 3: Influence of Nordic ball mill value on PM_{10} concentrations in the VTI road simulator hall.

Previous tests show that total wear is higher for AC (asphalt concrete) than SMA (stone mastic asphalt) pavements (Jacobson and Hornvall, 1999). Fields tests have not been able to confirm this effect for PM_{10} emission, but it is suggested that the direct emission often is overridden by road dust suspension in the field. No tests have, so far, been made on differences between AC and SMA in laboratory regarding particle emission.

Tests of alternative constructions show that concrete, in field tests, tend to reduce PM_{10} emission, but this may depend on driving lane (a few measurements have shown higher emissions in the left-hand driving lane) (Johansson and Karlsson, 2010). Repeated measurements are being made in 2012. In laboratory, concrete has been tested but results are not yet available.

Pavements with rubber mixed bitumen have, in laboratory, been shown to slightly reduce emissions while field tests do not support this result, showing no significant emission differences. Porous pavements, with an assumed capability to hold road dust away from suspension, have not been shown to reduce emissions in field tests. In laboratory lower emissions where attributed to the very wear resistant rock used, but no reference pavement was used in the test.

Table 1: Influence of pavement properties on PM_{10} wear emissions from laboratory and field studies performed in Sweden.

	Road simulator	**Field studies**
Asphalt		
Coarser D_{max}	+	+
Lower NBM	+	+
AC instead of SMA	No data	=
Rubber mixed bitumen	= +	=
Porous pavement	=[1]	=
Concrete	No data[2]	+

[1]No reference standard asphalt pavement was used.
[2]Results will be available at conference.

Discussion

The results from the overviewed projects show that there are many possibilities to reduce PM_{10} emissions from road pavements by changing their properties. For standard asphalt pavements, it is clear that the same properties that improve the overall wear resistance also reduce the PM_{10} emissions. Coarser and more wear resistant pavements will reduce emissions for these pavements. From a particle emission point of view this is positive, but at the same time these properties will have adverse effects. Noise emission is well known to increase as a result of coarse, stone rich and wear resistant pavements (Sandberg, 2002), causing the Nordic countries to have much noisier pavements than mid and south Europe. Traffic noise is, as particle pollution, an important health problem in cities, revealing a conflict between health related objectives. Also, need for more durable rock might cause higher costs and CO_2 emissions (due to transport to construction site) if not available nearby the road construction. Therefore, other secondary effects are important to consider when adjusting pavements for reduced PM_{10} emissions.

Alternative pavements and their possible effects on PM emissions are interesting, but still needs further evaluation before recommendations can be made. Interesting issues are the influence of concrete pavements as well as the possibilities of noise reducing pavements.

Reports summarised in this paper

Ordinary asphalt pavements

Gustafsson M, Blomqvist G, Dahl A, Gudmundsson A, Lindbom J, Ljungman A, et al, Inandningsbara partiklar från interaktion mellan däck, vägbana och friktionsmaterial. Slutrapport från WearTox-projektet. (Respirable particles from the interaction between tyres, carriageway and friction material. Final report from the WearTox project). (In Swedish, English abstract). VTI Report No 520, 2005.

http://www.vti.se/sv/publikationer/pdf/slitagepartiklar-fran-vagbelaggning-med-gummiinblandad-bitumen--jamforelser-med-referensbelaggning.pdf

Gustafsson M, Blomqvist G, Brorström-Lundén E, Dahl A, Gudmundsson A, Johansson C, et al, NanoWear – nanopartiklar från däck- och vägbaneslitage. (NanoWear – nanoparticles from tyre and carriageway wear). (In Swedish, English abstract). VTI Report No 660, 2009. . http://www.vti.se/sv/publikationer/pdf/nanowear--nanopartiklar-fran-slitage-av-dack-och-vagbana.pdf

Gustafsson M, Blomqvist G, Jonsson P. Damningsminimerad vinter- och barmarksdrift av belagda vägar. Mått, medel och strategier. VTI Rapport 701, 2009. (Dust-minimised winter and snow-free operation of paved roads). (In Swedish, English abstract). http://www.vti.se/sv/publikationer/pdf/slitagepartiklar-fran-vagbelaggning-med-gummiinblandad-bitumen--jamforelser-med-referensbelaggning.pdf

Gustafsson M, Blomqvist G, Gudmundsson A, Jonsson P, Swietlicki E. Vägbeläggningars damningsbenägenhet. VTI Rapport 711, 2011. (Dusting propensity of pavements. (In Swedish, English abstract). http://www.vti.se/sv/publikationer/pdf/slitagepartiklar-fran-vagbelaggning-med-gummiinblandad-bitumen--jamforelser-med-referensbelaggning.pdf

"Quiet" pavements (porous, rubber-admixed or of small aggregate size)

Gustafsson M, Blomqvist G, Gudmundsson A, Jonsson P. Slitagepartiklar från vägbeläggningar med gummiinblandad bitumen – jämförelse med referensbeläggning, (Abrasion particles from pavements with rubber-admixed bitumen - comparison with reference pavement). (In Swedish, English abstract). VTI Notat 10. 2009.

http://www.vti.se/sv/publikationer/pdf/slitagepartiklar-fran-vagbelaggning-med-gummiinblandad-bitumen--jamforelser-med-referensbelaggning.pdf

Gustafsson M, Blomqvist G, Bennet C. Slitagepartiklar från vägbeläggningar med gummiinblandad bitumen – jämförelse med referensbeläggning, (Abrasion particles from pavements with rubber-admixed bitumen - comparison with reference pavement). (In Swedish, English abstract). VTI Notat 8-2011. Statens väg- och transportforskningsinstitut, Linköping, 2011.

Johansson, C., Hussein, T., and Karlsson, H., 2007. Betydelsen av bullerreducerande beläggning för partikelemissionerna. (The significance of noise-alleviating pavements for particle emissions).(In Swedish). ITM report 164. ITM Stockholms universitet, 106 91 Stockholm, Sweden. ISSN 1103-341X. http://www.slb.nu/slb/rapporter/pdf/itm_rapp_164.pdf

Johansson, C., 2006, Betydelsen av bullerreducerande beläggning för partikelhalterna – Delrapport från forskningsprojekt. (The significance of noise-alleviating pavements for particle concentrations – Interim report from a research project. SLB rapport 2006:3. http://slb.nu/slb/rapporter/pdf8/slb2006_003.pdf

Nordberg, M. et al., 2007. Bullerreducerande beläggning för partikelhalterna. (Noise-alleviating pavements for particle concentrations). (In Swedish). Final report FUD 3066, SBUF 11748/11858. http://www20.vv.se/fud-resultat/Publikationer_000501_000600/Publikation_000588/slutrapport_071210_MN.pdfhttp://www20.vv.se/fud-resultat/Publikationer_000501_000600/Publikation_000588/slutrapport_071210_MN.pdf

Johansson, C., 2011. PM_{10} emission från tysta beläggningar i Stockholmsregionen. (PM_{10} emission from quiet pavements in the Stockholm Region. http://slb.nu/slb/rapporter/pdf8/itm2011_198.pdf

Concrete pavement

Johansson, C., Karlsson, H., Rosman, K. PM_{10} emission från betongbeläggning. (PM_{10} emission from concrete pavement). (In Swedish). Stockholm University, Report No:192. http://slb.nu/slb/rapporter/pdf8/itm2009_192.pdf

Johansson, C. & Karlsson, H., 2010. Measurements of the emissions of particulate matter (PM10) from a concrete compared to a stone mastic asphalt highway. Abstract presented at the 11th International Symposium on Concrete Roads, Sevilla, Spain, 13-15 October, 2010.

Acknowledgements

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Hussein T, Johansson C, Karlsson H, Hansson H-C. Factors affecting non-tailpipe aerosol particle emissions from paved roads: On-road measurements in Stockholm, Sweden. *Atmospheric Environment* 2008; 42: 688-702.

Jacobson T, Hornvall F. Beläggningsslitage från dubbade fordon (Pavement wear from vehicles with studded tyres), VTI notat 44, 1999, pp. 27.

Johansson, C. & Karlsson, H., 2010. Measurements of the emissions of particulate matter (PM10) from a concrete compared to a stone mastic asphalt highway. Abstract presented at the 11th International Symposium on Concrete Roads, Svilla, Spain, 13-15 October, 2010.

Sandberg U., Ejsmont J.A. (2002) Tyre/Road Noise Reference Book 1st Edition INFORMEX Esjmont & Sandberg Handelsbolag. Kisa.