Asphalt Rubber - a new concept for asphalt pavements in Sweden.

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ABSTRACT: 'Asphalt Rubber' is a bitumen, mixed with 15 to 20 % of rubber granules from recycled tyres to improve the functional properties of asphalt pavements. The 'Asphalt Rubber'-concept for asphalt pavements has been successfully implemented in a number of US states. The Swedish Road Administration (SRA) is currently involved in investigating the potential implementation of this concept in asphalt pavements through a three-year development project (2007-09). This paper presents promising test results from trials with asphalt rubber pavement materials from the ongoing projects and evaluation studies.

KEYWORDS: *'Asphalt Rubber', performance, environmental effects, Sweden, Swedish Road Administration*

1. Introduction

During the autumn 2006 the Swedish Road Administration (SRA) decided to start a development project for the period of 2007 - 2009 to investigate the potential implementation in Sweden of asphalt pavements, produced according to the 'Asphalt Rubber'-concept. This concept, based on the 'wet technique', was developed in the United States (US) and has been established in a number of states. 'Asphalt Rubber' has been produced in a large scale in US since the end of the 1980's. The international interest for 'Asphalt Rubber'-pavements has grown in recent years. At present the 'Asphalt Rubber'-concept is being established in several countries.

'Asphalt Rubber' can be characterized as a rubber-modified bitumen, where rubber granules have been mixed with a standard bitumen ('wet technique'). The rubber granules originate from used tyres. The 'Asphalt Rubber' is manufactured in a specially developed mixing equipment. The equipment is mobile and placed in connection to the asphalt plant, producing the asphalt mix. The mixing of the components is carefully controlled and followed by a procees of maturity. The content of rubber granules is 15 to 20 % of the mass of the binder or 1,5 to 2,0 % of the mass of the asphalt mixture.

The expected long-term effects and potential benefits of the project are reduced annual and life cycle costs, environmental advantages with respect to noise and emission of particles, and also improved traffic safety in terms of increased friction. Within the frame-work of the present project the following issues are evaluated:

- Technical conditions and possibilities for production
- Environmental effects and restrictions
- Technical performance of asphalt mix/pavement.

The evaluation is based on field trials/demonstration projects, where the performance (functional properties) and possible influence on work environment as well as environment of surroundings will be monitored.

Special focus is on the environmental consequences (both work environment and environment of surroundings). The Swedish Chemical Agency has recommended a restrictive use of old rubber tyres, in reference to their high contents of polycyclic aromatic hydrocarbonates (PAH).

Asphalt pavements with rubber granules have been previously produced in Sweden, but not according to the above 'wet technique'. Instead a 'dry technique' was used, where the rubber granules were added to the aggregate before the mixing with bitumen at the asphalt plant. The main problem with this type of rubber asphalt was the varying quality. The 'wet technique' according to the 'Asphalt Rubber'-concept makes it possible to produce rubber asphalt pavements of high and uniform quality.

This paper presents a progress report as of February 2009 regarding the Swedish experience in 2007-2008 from asphalt pavements, produced according to the ‘Asphalt Rubber’-concept..

2. Motives for the project

The Swedish Road Administration (SRA) considers that the ‘Asphalt Rubber’-development project is a project of great economic importance and expects that the introduction of ‘Asphalt Rubber’-pavements on the Swedish road net will result in

1. Reduced annual and lifecycle costs;
2. Environmental advantages, concerning reduction of noise and particle emissions;
3. Increased traffic safety;

Reduced annual and life cycle costs

Based on international experience the service life of ‘Asphalt Rubber’-pavements can be doubled in comparison with corresponding standard pavements. Due to the uncertain influence of studded tyres in Sweden on the service life of the ‘Asphalt Rubber’-pavements, it is assumed that only half of the expected increase in service life can be utilized. The estimated increase in costs for construction of the ‘Asphalt Rubber’-pavement is about 25 %. This means that the annual cost for ‘Asphalt Rubber’-pavements will be about 80% of the annual cost for the standard pavements. The annual maintenance cost for SRA’s asphalt pavements in Sweden amounts to about 250 million Euro. Given that the ‘Asphalt Rubber’-pavements are a marketable alternative, representing 25 % of that volume, the annual maintenance cost could be reduced around 10 million Euro.

Environmental advantages

The tyre noise and the emission of particles, due to abrasion from studded tyres, are expected to decrease and improve the environment.

Improved traffic safety

The traffic safety is expected to be improved on rain wet road surfaces by higher friction between road surface and tyre and reduced formation of ‘water curtains’.

3. Objectives of the project

The project shall demonstrate the prospects for development and implementation of the ‘Asphalt Rubber’ concept for pavements on the Swedish road net. The main objectives of the project are

1. Verification of the possible production of high quality ‘Asphalt Rubber’-pavements in Sweden;
2. Verification of increased service life and reduced annual and life cycle costs;

3. Verification of environmental advantages;
4. Verification of management of possible health and environmental risks;
5. Verification of advantages considering traffic safety.

4. Preparatory actions and studies

The supply of technical expertise has been ascertained by engaging leading equipment suppliers for manufacturing of rubber-modified bitumen. Contracts, covering both machine and personal resources, have been established. In SRA’s own organisation the necessary technical competence will be utilized during the accomplishment of the project.

A comprehensive preliminary study, including technical issues such as production engineering and product quality, has been carried out during 2006.

Environmental aspects have also been studied by literature review and laboratory testing and the preliminary results indicate that the environmental risks should be very limited. Further studies of effects on health and environments form an integral part of the project and shall be carried out in conjunction with full-scale trials.

5. Scope and time schedule of the project

The project activities during 2007-2010 are as follows.

2007 - Construction of experimental ‘Asphalt Rubber’-pavements on roads in the southern and central parts of Sweden. Mixing equipment was supplied by SRA. Evaluation of the hitherto achieved results. Decision was taken to continue the project.

2008 - Extended construction of experimental ‘Asphalt Rubber’-pavements, involving different regional departments of SRA. Mixing equipment was supplied by SRA. Evaluation of the hitherto achieved results. Decision was taken to continue the project.

2009 - Continued construction of experimental ‘Asphalt Rubber’-pavements, involving different regional departments of SRA. Mixing equipment is supplied by SRA. Evaluation of the hitherto achieved results. Preparation of the final report. Draft technical specification for ‘Asphalt Rubber’-pavements will be presented.

2010 - The procurement of the ‘Asphalt Rubber’-pavements will start. Project information will be disseminated to suppliers and contractors to instil a genuine interest in the ‘Asphalt Rubber’-concept and to create a potential market for ‘Asphalt Rubber’-pavements.

6. Manufacture and evaluation of the 'Asphalt Rubber'-binder

The rubber granules and the manufactured 'Asphalt Rubber' are specified according to the Arizona Department of Transportation "Standard specification for Road and Bridge Construction, 2000".

The rubber modified bitumen is manufactured in a specially designed mixing equipment. It is mobile and placed in connection to the asphalt plant, producing the asphalt mix. See Figure 1.

The rubber granules (see Figure 2) are produced by fragmentation and sieving of recycled tyres, including separation of steel and fibre reinforcements. The rubber granules are mixed with normal standard bitumen in a closed process. When the Asphalt Rubber mix has the designed viscosity (normally 2, 5 – 3 Pas) it is ready for use as a normal bitumen in the asphalt production. The content of rubber granules is 15 to 20 % of the mass of the binder or 1,5 to 2,0 % of the mass of the performed asphalt pavement.

The mixing equipment, used by SRA, is rented from the equipment supplier Phoenix Industries LLC (PI), Arizona. Technical experts from PI have also been responsible for training in production technique and technical support.

Figure 1. Mixing equipment connected to the asphalt plant

Figure 2. Rubber granules, used in SRA´s trials

Before the road trials of 2007 and 2008, the 'Asphalt Rubber'-binder (AR) as well as the trial mixes, produced with this binder, has been thoroughly evaluated in the laboratory to ensure the right quality of the manufactured products. The rubber content of the rubber/bitumen-mix has been 16-19 %. The target viscosity at 175 °C after a reaction (mature) time of 45-60 min has been 2 to 3 Pas.

On the construction site the AR-viscosity is regularly controlled by a manual field viscometer. If the viscosity is deviating from the target value, the rubber content is adjusted to get the correct viscosity. The AR production temperature has been in the range of 170 to 175 °C.

Samples of the rubber granules and the manufactured AR are taken continuously and analysed at a certified laboratory. The basic bitumen consists of pen grade 70/100. The rubber granules have been purchased mainly from two suppliers, Genan in 2007 and Eximlink in 2008. AR-gradings, supplied by Genan, are shown in Figure 3.

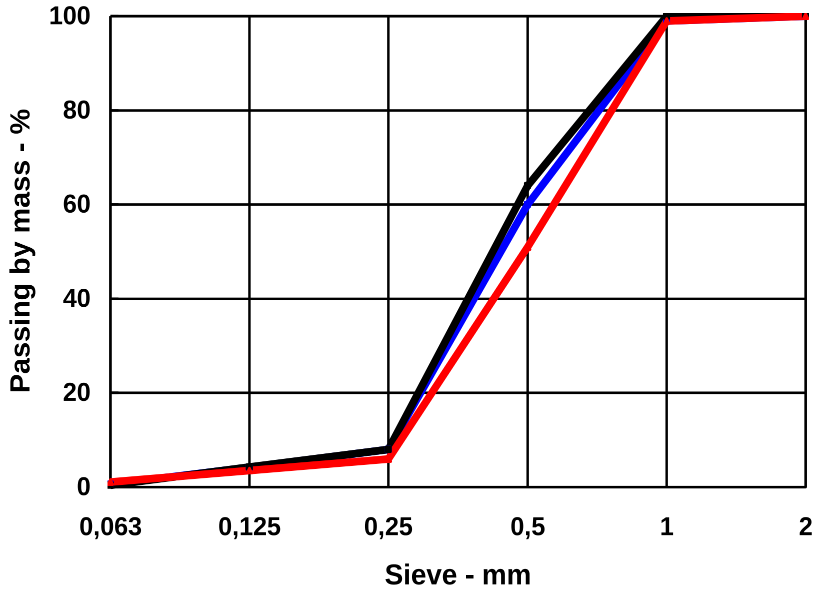

Figure 3. Three typical gradings of rubber granules from the production in 2007.

7. Specifications and production of the 'Asphalt Rubber'-mix

The specifications of the 'Asphalt Rubber'-mixes for the road trials are based on the Arizona Department of Transportation "Standard specification for Road and Bridge Construction, 2000". Certain modifications of the specifications for gradings and void contents have been made to fit the Swedish practice for surface course pavements.

During 2007 and 2008 nearly 30 000 ton of 'Asphalt Rubber'-mixes have been produced. The major part of the produced mixes was Stone Mastic Asphalt (SMA) - mixes, designated SMA 11 and 16. However, the filler content and the content of fine aggregate 0/2 mm have been decreased to provide room for the rubber granules (see Figure 4). The target added content of 'Asphalt Rubber' has been in the range of 8,3 to 9,0 % by mass. For the mix design the target void content, provided by Marshall impact compaction at a compaction temperature of about 170 °C, has been 2,0 to 2,5 %. The temperature at the production of the 'Asphalt Rubber'-mix has been 165 to 170 °C.

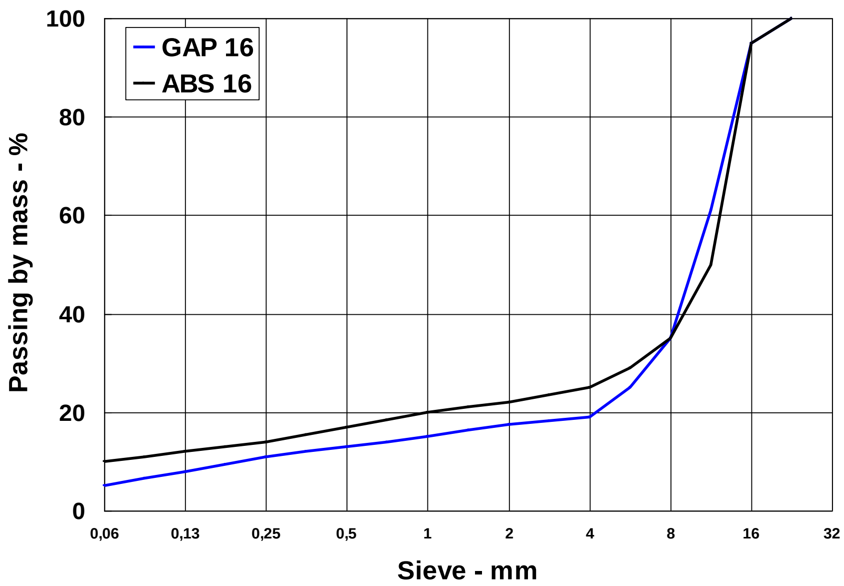

Figure 4. Typical aggregate gradings for the 'Asphalt Rubber'-mix, GAP 16, and the reference mix, SMA 16

Two interesting minor trials with an open-graded (void content > 15 %), low noise 'Asphalt Rubber'-pavement, based on the concept used in Arizona, have also been carried out. However, it was observed that this concept needs some adjustment and development, mainly because of the studded tyre use during the winter in Sweden.

8. Evaluation of performance and functional properties of the 'Asphalt Rubber'-mix/pavements

Asphalt mixes and constructed pavements, involved in the project, are studied by a comprehensive monitoring programme, including field observations and measurements and extensive laboratory studies of primarily the achieved functional properties.

ASU (Arizona State University) in Phoenix and VTI (Swedish Transport and Road Institute) in Linkoping have been engaged in cooperative work on laboratory studies. Also different contractor laboratories have been involved in the factory production control and quality control and evaluation of the constructed 'Asphalt Rubber'-pavements.

ASU has studied two asphalt mixes, laid on road E6 in the vicinity of Malmoe 2007 and consisting of a 'Asphalt Rubber'-mix, GAP 16 (a gap-graded asphalt mix with a nominal upper aggregate size of 16 mm) and a reference asphalt mix, SMA 16 (stone-mastic asphalt mix with a nominal upper aggregate size of 16 mm and a penetration bitumen with grade 70/100). The results of this study are reported separately in these AR2009 conference proceedings.

In this paper some results from the VTI study, based on the test methods used in Sweden are presented. At VTI the main part of the studies has been carried out on cores, extracted from the pavement on the outer ring-road in Malmoe, constructed in 2007. The principal purpose of the 'Asphalt Rubber'-mix, laid on this test section, is to counteract the crack propagation from the underlying courses. The existing pavement, constructed during 2000-2001, is a conventional asphalt pavement of 10 cm thickness (4 cm surface course and 6 cm binder course), laid on a cement bound granular base. Extensive reflection cracks from the underlying cement bound base course appeared shortly after the traffic opening in 2001.

9. Testing conducted by VTI in Sweden

Functional properties such as flexibility **(**stiffness at different temperatures) resistance to fatigue, stability, resistance to abrasion from studded tyres and durability are essential for the assessment of the quality of an asphalt pavement. At the VTI study most functional properties have been determined by test methods, which are in line with current European test standards. Special test procedures, developed at VTI, have been used for the winter conditioning and crack propagation tests. See Table 1.

Table 1. Test methods used at the VTI study

Property	Type of test	Method used by VTI	Corresponding European Standard
Stiffness	Indirect tensile test	FAS Metod 454[a]	EN 12697-26
Resistance to fatigue	Indirect tensile test	VTI own method	EN 12697-24
Stability (Resistant to permanent deformations)	Uniaxial cyclic compression test with confinement (Dynamic creep)	FAS Metod 468[a]	EN 12697-25
Resistance to abrasion from studded tyres	'Prall'-test	FAS Metod 471[a]	EN 12697-16
Water sensitivity	Indirect tensile test	FAS Metod 446[a]	EN 12697-12
Durability – sensitivity to winter conditioning	Freeze-thaw cycles with saltwater; reduction of stiffness modulus	VTI's own method	Stiffness modulus according to EN 12697-26
Crack propagation sensitivity	Wheel-tracking test	VTI's own method	Wheel-tracking machine according to EN 12697-22

[a]Test method prepared by FAS, the former Swedish Asphalt Pavement Association.

9. Results of the VTI study

The results are based on cores, extracted from an 'Asphalt Rubber'-pavement, laid on the outer ring-road E 6 between the Sallerup and Fredriksberg interchanges. Cores with 100 mm and 150 mm diameters, sampled September 2007. have been dispatched to VTI. Some results are presented below. The complete results will be presented in a future VTI-publication.

9.1. Stability according to the dynamic creep test

The results of the stability/dynamic creep test are shown in Figure 5. The mean accumulated strain after 3600 load cycles amounts to 14 500 microstrains and fulfils the most strict requirement (<15000 microstrains) for surface courses according to SRA´s technical specifications, 2008.

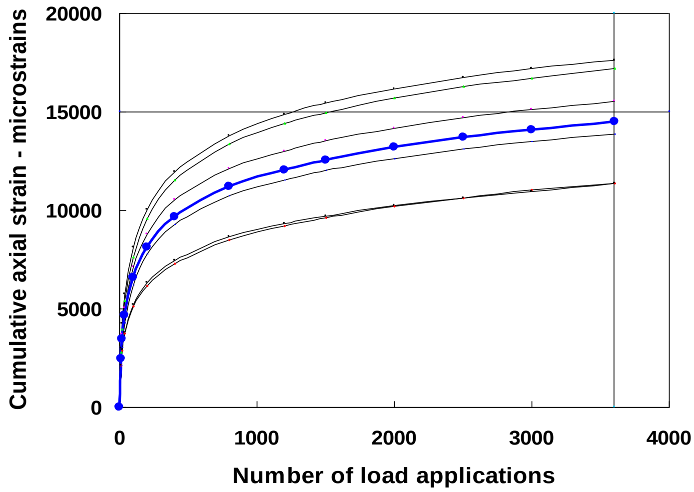

Figure 5. Accumulated strain as a function of the number of load cycles at 40 °C (single test specimens: black curves; blue average curve).

9.2. Resistance to fatigue

The loading of the fatigue test was applied in the same way as the loading of the stiffness test and continued, until failure occurred in the test specimen. The 'Asphalt Rubber'-test specimens sustained about 1 million load applications at 100 microstrains and satisfied the most strict fatigue requirement of SRA´s technical specifications, 2008.

9.3. Crack propagation sensitivity

VTI has developed a special test procedure for determination of the crack propagation sensitivity of the rubber asphalt, based on VTI´s wheel tracking machine (WTT), specified under clause 6.2 'Extra large devices' in EN 12697-22. Test slabs are placed in the wheel-tracking device on a divided soft rubber base in order to generate cracks through the pavement slab. Duplicate strain gauges are mounted on the lower and upper surface of the slab, enabling recording of the crack propagation course from the bottom to the top of the slab. The test was conducted on 3 slabs, prepared using the 'Asphalt Rubber'-mix, and 3 slabs, prepared using the reference asphalt mix, SMA 16 (bitumen 70/100).

<u>Test conditions</u>

Slab size:	50 x 70 x 4 cm (slab mass ≈ 30 kg).
Temperature:	+5 °C.
Wheel load:	Adjusted to the desired strain level
Number of wheel passes:	Adjusted to the crack propagation

The number of wheel passes to initiate cracking at the bottom and at the top of the slab are recorded at a given level of initial strain (= recorded strain after 100 wheel passes). The initial strain reflects the load applied to the test specimen. The difference between the two numbers of wheel passes is a measure of the crack propagation rate of the test specimen. The results for the six test slabs are shown in Figure 6. The rubber asphalt slabs are less sensitive to crack propagation at the same initial strain level than the reference slabs.

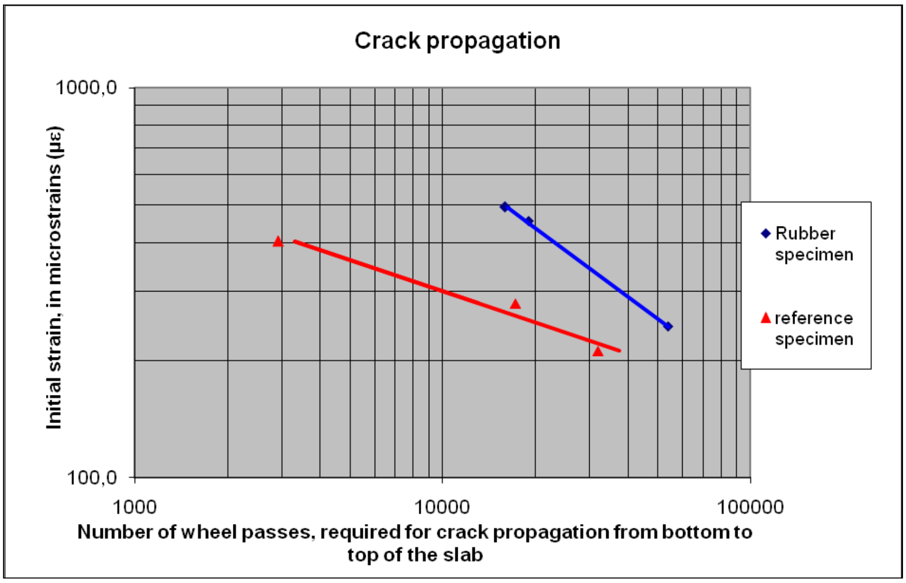

Figure 6. Effect of initial strain on the required number of wheel passes to cause complete crack propagation of the rubber asphalt and reference test specimens.

9.4. Sensitivity to winter conditioning

The winter conditioning method has been developed at VTI by Peet Höbeda. The conditioning phases are intended to simulate those stresses that roads are exposed to with alternating temperatures around zero in combination with salting. The effect of the conditioning is assessed by measuring the stiffness modulus. The ratio of the stiffness modulus before and after the conditioning is designated Q-winter and expressed in percent (if Q-winter is 100 %, the winter conditioning has no influence). The advantage of the stiffness modulus test, besides its sensitivity to variations of the properties of the test specimen, is its non-destructive mode, i.e. the same test specimen can be tested before and after conditioning. In this case the winter conditioning did not reduce the stiffness modulus of the ‘Asphalt Rubber’-test specimens; the actual Q-winter value was equal to or greater than 100 %.

10. Environmental studies

Comprehensive studies have been carried out to explore the impacts of the ‘Asphalt Rubber’-concept on the work environment and the environment of surroundings.

10.1. Work environment

Initially a laboratory study was conducted, where bitumen fumes were generated at 160 ^{0}C and cooled down to a condensate. The condensate was analysed chemically to get a picture of what substances could be found in the different bitumen products. The programme for the field measurements was established based on the results from this study. The measurements on the paving site included the content of polycyclic aromatic hydrocarbons (PAH), released from bitumen and asphalts with rubber additives at six different pavement sites during 2008. Measurements were conducted in the inhalation zone of the paver operator and the screed operators, above the augers of the paver and also on the workers at the production unite for ‘Asphalt Rubber’.

The results of the measurements were as follows.

1. The highest PAH-contents arose directly above the augers. The maximum benso(a)pyrene and naphthalene contents of the inhalated air was far below the limiting values

- 0,03 µg/m^{3}of benso(a)pyrene << threshold limit value = 2 µg/m^3;
- 2,4 µg/m^{3}of naphthalene << threshold limit value = 50 000 µg/m^3;

2. More PAH was released, when the mixture was strongly heated, as by using a heater especially in combination with remixing.

3. The PAH-exposure was lower at the plant, where rubber was added, than around the asphalt paver at the site. The wind direction and velocity in conjunction with the temperature of the asphalt mix appeared to be the factors controlling the degree of exposure at the paver.

10.2. Leaching tests

The Swedish Geotechnical Institute (SGI) in Linkoping has investigated the leaching of organic substances and compounds from road normal asphalts, produced with and without additives of rubber (from recycled tyres), granulated to particles < 20 mm.

The leaching contents of most of the analysed substances and compounds were low for both materials. The acute toxic effects of the leachate were also low.

The rubber additive caused somewhat increased leaching of other PAHs and of cresoles. However, the contents and the accumulated amounts of these compounds were generally low. There was no carcinogen PAH above the detection limit in any leachate.

The rubber additive generated leaching of bensotiazol, detected by GCMS-screening. The estimated contribution of semi-quantative and accumulated leached contents of bensotiazol to the nearby surroundings of the road were considerably higher for the asphalt with added rubber. However, the preliminary assessment, based on the US limiting value for a closely related compound in surface and ground water, is that leached bensotiazol should not generate any serious contents in leachates, caused by rain on the monolithic road surface of the material. There was also no relation between leached bensotiazol and acute toxic effects.

10.3. Particle emission caused by abrasion from studded tyres

VTI has studied the emission of inhalable abraded particles, using the road test machine, shown in Figure 7. Two runs were conducted; one run with an 'Asphalt Rubber'-pavement, GAP 16, and the other one with a reference pavement, SMA 16. The particle size distribution of the emitted particles and their chemical and morphological properties were analysed, especially PM_{10} (= the mass concentration of inhalable particles finer than 10 µm, expressed in $\mu g/m^3$), which is regulated by an EU directive and implemented in Sweden as an environmental quality standard.

Altogether, the results showed that the 'Asphalt Rubber'-pavement contributed to lower emissions of both PM_{10} and ultra fine particles than the reference pavement.

Figure 7. VTI road test machine for abrasion and particle studies

11. Concluding remarks

The overall experiences from the studies so far are positive, and there is no reason to discontinue the project. The results from the comprehensive tests and investigations, covering technical, performance-related and environmental aspects, are in agreement with the results, obtained in US.

The remaining parts of the project include:

- Development of a cost effective management of the equipment for involving rubber in the asphalt production process;
- Reduction of the production temperature, which is advantageous for the working environment as well as the emissions to the surroundings.
- Further development of the concept of 'Asphalt Rubber'- pavements for "low noise pavements" to improve the resistance to abrasion from studded tyres.

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