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Generation of urban road dust from anti-skid and asphalt concrete aggregates

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Abstract

Road dust forms an important component of airborne particulate matter in urban areas. In many winter cities the use of anti-skid aggregates and studded tires enhance the generation of mineral particles. The abrasion particles dominate the PM_{10} during springtime when the material deposited in snow is resuspended. This paper summarizes the results from three test series performed in a test facility to assess the factors that affect the generation of abrasion components of road dust. Concentrations, mass size distribution and composition of the particles were studied. Over 90% of the particles were aluminosilicates from either anti-skid or asphalt concrete aggregates. Mineral particles were observed mainly in the PM_{10} fraction, the fine fraction being 12% and submicron size being 6% of PM_{10} mass. The PM_{10} concentrations increased as a function of the amount of anti-skid aggregate dispersed. The use of anti-skid aggregate increased substantially the amount of PM_{10} originated from the asphalt concrete. It was concluded that anti-skid aggregate grains contribute to pavement wear. The particle size distribution of the anti-skid aggregates had great impact on PM_{10} emissions which were additionally enhanced by studded tires, modal composition, and texture of anti-skid aggregates. The results emphasize the interaction of tires, anti-skid aggregate, and asphalt concrete pavement in the production of dust emissions. They all must be taken into account when measures to reduce road dust are considered. The winter maintenance and springtime cleaning must be performed properly with methods which are efficient in reducing PM_{10} dust.

Keywords: Road dust; Mineral particles; PM_{10}; SEM/EDX; Anti-skid and asphalt concrete aggregates; Paved roads; Studded tires; Hazardous dust; EU limit value

1. Introduction

Road dust has been acknowledged as a dominant source of PM_{10} (particulate matter, aerodynamic diameter <10 μm) especially during spring in many winter cities of Scandinavia, North America, and Japan and causes serious environmental problems [1–5]. Urban road dust is a complex mixture of particles released from several different sources. It is an important component of urban PM_{10} and its composition is usually dominated by geological material [4,6–10]. In addition to many kinds of discomfort, road dust causes negative health effects. Studies of exposure to mineral and resuspension particles have shown evidence of toxicity and a possibility of adverse health impacts [11–13]. Respirable mineral particles, e.g. aluminosilicates and crystalline quartz, have been implicated in human diseases with lung cancer as most severe [14–16]. Paved road dust is also a source of allergen exposure for the general population [17].

The high proportion of road dust has been linked to the snowy winter conditions that makes it necessary to use traction control methods. These measures enhance the generation of mineral particles. A fraction of the particles is deposited in snow and later released when the snow melts. These abrasion particles are observed in high concentrations, especially during spring in urban areas with high volumes of traffic [4,18].

The methods for traction control include dispersion of anti-skid aggregates on the road surface and equipping the tires with metal studs or a special rubber design. High particle concentrations have been connected in, e.g. Japan and Norway [1,2,19,20]

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to the use of studded tires which also produce direct emissions from wearing of bare asphalt concrete. The use of anti-skid aggregates has also been linked to an increased particle loading in urban air [3,21,22]. The formation processes of the particles are the mechanical wear of the actual anti-skid aggregate grains and the wear of asphalt pavement both by tires and by anti-skid aggregate particles [21].

Urban road dust is an important issue also from the viewpoint of the European Union limit values for airborne particles (daily maximum for PM_{10} is $50\,\mu g\,m^{-3}$, allowing 35 exceedances annually). This limit value is commonly exceeded in many Scandinavian cities due to springtime road dust. The Council Directive 1999/30/EC allows member states to designate the zones within which the limit values are exceeded due to the resuspension of particulates following the winter sanding of roads. This statement challenges to study the impact of anti-skid aggregates on PM_{10} concentrations.

The aim of this work was to study experimentally the factors that affect the generation of abrasion components of road dust from the two mineral dust sources, asphalt concrete and anti-skid aggregates. This paper presents the main results from three test series. Some of the results are reported in [21,23,24].

2. Experimental

2.1. The test facility and aggregates

This study was conducted in a test facility, which made it possible to rule out dust contributions from other sources than abrasion of asphalt concrete or anti-skid aggregates, and tires. The test room ($180\,m^3$ in volume) was cooled to a temperature of 0–2 °C to represent the temperature in dry spring conditions. RH was 50–75%. Two wheels were attached to an electrically powered rotating axel, with adjustable rotating speed. The axel system was tuned to move sideways so that the driving space of the tires becomes 33 cm. The diameter of the test ring was 390 cm. The tire pressure was 2.0 bar and the weight for each tire was 300 kg. The driving ring was surrounded with low walls to prevent the traction sand from flying off.

The impact of anti-skid aggregates on suspended PM (PM is used for all airborne particulate matter, since the concentrations of total suspended particles [TSP] were measured) was studied by using different amounts of sanding aggregates having various particle size distribution and different modal composition. It is difficult to estimate the shares of the different mineral dust sources, because they often have a similar mineralogical composition [25]. For these tests, aggregates (anti-skid and asphalt concrete aggregates) with distinguishable mineralogy were chosen to be able to estimate the proportions from different dust sources. Tested asphalt concrete and anti-skid aggregates are also used in real life. The modal compositions of tested aggregates are given in Table 1. In tests during 2001–2002 only the asphalt concrete aggregate (mafic volcanic rock) contained the mineral hornblende, which was used as a tracer for the mineral dust from the asphalt concrete pavement. In 2003 tests the asphalt concrete aggregate was granite, and its minerals quartz and potassium feldspar were used as tracers because anti-skid aggregates did not contained these minerals. Three test series and a total of 59 tests were performed.

Tests were performed with studded and friction tires to investigate asphalt concrete pavement wear and suspended PM generation caused by different tires. Different amounts of anti-skid aggregates were distributed (0, ∼300, ∼1000, and $\sim 2000\,g\,m^{-3}$) including four different natural anti-skid aggregates and blast furnace slag anti-skid aggregate. An amount of traction sand was chosen to represent dirty road conditions found in springtime when traction sand is accumulated on the pavement for a long time. Two rock types were used as asphalt concrete aggregates to study the role of asphalt concrete aggregates in the PM generation. The impact of driving speed was studied using low speeds (either 15 or $30\,km\,h^{-1}$). The results showed the factors that affect the emissions as well as the relative importance and the possible magnitude of the effect of these factors. The facility and the test descriptions are presented in more detail in Kupiainen et al. [21,23,26] and Räisänen et al. [24,27].

Table 1
The modal compositions (%) of aggregates

	Aggregates				Chemical formula
	Granite 1 Sanding 2001–2002	Granite 2 (Pernaja) Asphalt 2003	Diabase Sanding all tests	Mafic volcanic rock (Patavuori) Asphalt 2001–2002, sanding 2003	
Quartz	30.4	28.4			SiO_2
K-feldspar	29.6	26.3			$KAlSi_3O_8$
Plagioclase	32.4	39.4	57.4	29.4	$(Na, Ca)Al(Si, Al)Si_2O_8$
Biotite	5.9	1.8	3.8		$K(Mg, Fe)_3(Al, Fe)Si_3O_{10}(OH, F)_2$
Hornblende				53	$Ca_2(Mg, Fe)_4Al(Si_7Al)O_{22}(OH, F)_2$
Clinopyroxene			17.3		$(Ca, Mg, Fe)_2Si_2O_6$ (Augite)
Olivine			17.5		$(Mg, Fe)_2SiO_4$
Cummingtonite-grunerite				12.8	$(Mg, Fe)_7Si_8O_{22}(OH)_2$
Others	1.7	4.1	4	4.8	
STT	20.7	5.2	11.6	6.2	
LA 10–14/4–5.6	42/43	15/24	16/23	11/17	

Mafic volcanic rock was used as an asphalt concrete aggregate in 2001–2002 and as an anti-skid aggregate in 2003. Granites were used as anti-skid aggregate in 2001–2002 and as asphalt concrete aggregate in 2003. STT: studded tire test value [30]; LA 10–14/4–5.6: Los Angeles test value for 10–14/4–5.6 mm [29].

The particle size distribution of anti-skid aggregates was determined with sieves from 0.063 to 8 mm [28]. The Los Angeles test (LA) was used to determine aggregates' resistance to fragmentation [29] and it was performed from fractions 10/14 to 4/5.6 mm, the latter according to Annex A with eight balls. The studded tire test (STT) measures the ability of an aggregate to tolerate the abrasive wear of studded tires [30]. Point-counting method with a polarizing microscope was used to determine the modal composition of studied aggregates. The petrographical and mechanical-physical properties of the aggregates used in the tests are presented in more detail in Kupiainen et al. [21,23,26] and Räisänen et al. [24,27].

2.2. Particle sampling and analysis

Two high volume samplers (Wedding & Associates Sampler—TSP and PM_{10}) were used to measure the concentrations of suspended particles and to collect samples for the analyses of PM. In one test series the size distribution of the aerosol was studied and samples were collected for a more detailed PM research using two virtual impactors (VI—$PM_{2.5–10}$ and $PM_{2.5}$) and two 12 stage (0.045–10.7 μm) cascade impactors (SDI, [31]). The VIs were equipped with (Pallflex, type Tissuquartz 2500QAT-UP) quartz and (Millipore, type FS3-μm) Polytetrafluoroethylene(PTFE) filters, the SDI with aluminium substrates and (Whatman, type Nuclepore 800120) polycarbonate membranes and the high volume samplers with glass fiber filters (Munktell, type MG160). All inlets were situated similarly, approximately 1.5 m of the driving ring at a height of 2.5 m. After each test, the dust was allowed to settle for 30–45 min, and after that, the room was vacuumed and ventilated. Background concentration was monitored before the tests. The average background was less than 10% of the lowest concentration measured in the tests.

The morphology, composition, and mineralogy of the particles were determined from high volume TSP- and PM_{10}-filters, and the cascade impactor membranes with individual particle analysis by a scanning electron microscope (SEMZEISS DSM 962) coupled with an energy dispersive X-ray analyzer (EDXLINK ISIS with ZAF-4 measurement program). A similar instrumentation has been used in several particle studies [32–37]. The analytical method is described in Kupiainen et al. [21,23].

The morphology and chemistry of fine and submicron particles were studied in detail from the polycarbonate membranes of the cascade impactor. A field emission SEM (FESEMJEOL JSM-6335F) coupled with an energy dispersive X-ray microanalyzer (EDXLINK ISIS and INCA) was used for the analyses. Samples were prepared similarly as for conventional SEM, with Cr as the coating material. The acceleration voltage was 15 kV.

The source contributions from asphalt concrete and sanding (in Figs. 2, 3 and 5) were estimated by comparing the abundance of minerals in the PM_{10} samples with the mineralogy of the asphalt concrete and sanding materials [21,23]. Comparison of five individual analyses from the same PM sample (studded tires, 1000 g m^{-2} of granite 1) is shown in Kupiainen et al. [23]. Based on that comparison the error for source contributions is estimated to be approximately 12%. This error is indicated in Fig. 3 with error bars.

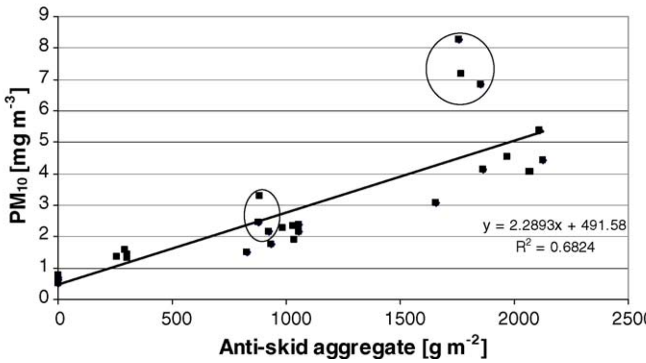

Fig. 1. The correlation between PM_{10} concentrations and the amount of anti-skid aggregate used in tests with the studded tires. The aggregate with lowest resistance against fragmentation (granite 1, inside circles) caused higher emissions than aggregates having higher LA-values, especially with higher amounts of anti-skid aggregate. Mafic volcanic rock used as asphalt concrete aggregate.

The carbonaceous fractions, elemental carbon (EC), organic carbon (OC), and carbonate carbon, were determined from the VI-quartz filter samples with a thermal–optical analyzer [38,39].

3. Results

3.1. Impacts of sanding on dust generation

Very high increase in PM_{10} concentrations was observed as a function of the amount of anti-skid aggregate dispersed on the asphalt concrete surface (Fig. 1 includes tests with studded tires). The concentrations were two fold with ~300 g m^{-2} of anti-skid aggregate, four fold with ~1000 g m^{-2} of anti-skid aggregate, and nine fold with 2000 g m^{-2} compared with the experiments without the sanding. The dust concentrations correlated with the amount of anti-skid aggregate even though different sanding and asphalt concrete materials were used.

The presented particle concentration data (Fig. 1) would lead to conclude that the PM_{10} dust originates mainly from sanding. This data does not, however, give any indication of the origin of the particles. The sources of the dust were investigated by an individual particle analysis studying the amount of particles originating from anti-skid and asphalt concrete aggregates. This was performed by measuring the fraction of different minerals in the PM_{10} samples and comparing these fractions to the modal composition of the rocks (see Section 2).

Fig. 2 presents results from tests which show the impact of sanding on the modal composition of PM. Mafic volcanic rock was used as an asphalt concrete aggregate and granite as an anti-skid aggregate. Tests without anti-skid aggregates were used as a reference to show the mineral composition of PM from only asphalt concrete abrasion. Since all the hornblende must originate from the asphalt concrete aggregate, its abundance was used as a basis to study the sources of the particles. Fig. 2 shows that when anti-skid aggregate was used, the share of hornblende decreased and shares of quartz and K-feldspar increased compared with the test without sand (asphalt-ref) indicating that dust was originated both from asphalt concrete and anti-skid

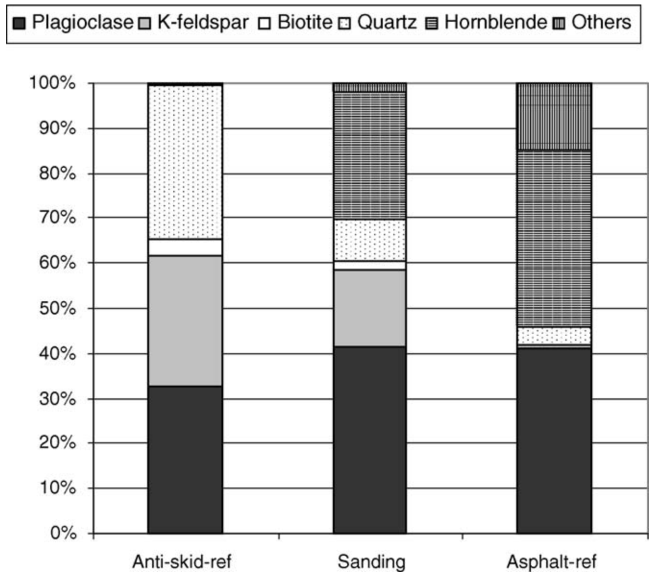

Fig. 2. The modal composition of PM_{10} samples (studied by SEM/EDX);
anti-skid-ref: the modal composition of the anti-skid aggregate (granite);
sanding: the modal composition of dust sample PM_{10} in the test with $1000\,g\,m^{-2}$ of this anti-skid aggregate;
asphalt-ref: the modal composition of dust sample PM_{10} in the test without anti-skid aggregate (mafic volcanic rock as asphalt concrete aggregate).

aggregates. This analysis of the dust by SEM/EDX showed that a large percentage of the particles (32–97%; 70% on average, see [21]) originated from the asphalt concrete.

The use of anti-skid aggregates greatly increased the PM_{10} concentrations but the source of the particles in these experiments was predominantly from the asphalt concrete pavement. It was concluded from the analyses of the particle concentrations and of the particle chemistry that the anti-skid aggregate was not only crushed into small PM_{10} particles but also increased the asphalt concrete wear. This phenomenon was named as "the sandpaper effect". Kanzaki and Fukuda [40], and Lindgren [41] have previously suggested that loose particles (e.g. scraped off the road surface) may work as grinding material and increase the wear. Fig. 3 demonstrates the sandpaper effect. Two tests were performed without anti-skid aggregate. PM in these cases was generated only from asphalt concrete. The white line shows the maximum PM_{10} concentration level of these tests. Anti-skid aggregate was used in all other tests. All the asphalt concrete-based PM above this line indicates PM generation by the sandpaper effect, which was a major source for suspended PM.

3.2. Impacts of asphalt concrete aggregates

The granite anti-skid aggregates with different grain size distribution was used to study the impact of the grading on the dust concentrations. The comparison of in tests (Fig. 4) shows that high percentage of fine-grained anti-skid aggregate particles of overall grading greatly increased the PM_{10} concentrations when high amounts of sand were dispersed. This impact was observed both with studded and friction tires. PM from both the anti-skid aggregate and from asphalt concrete aggregate increased. When

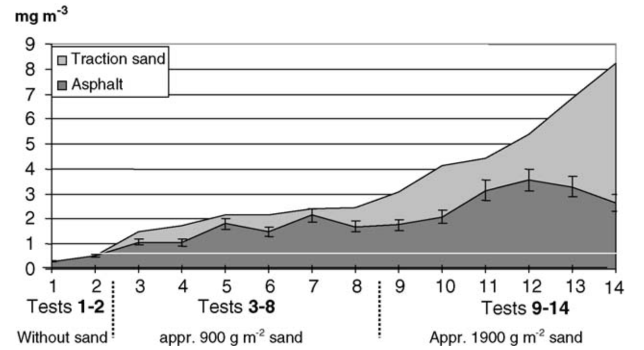

Fig. 3. The fractions of PM_{10} concentrations from the anti-skid aggregate (traction sand) and from asphalt concrete as a function of increased sanding; mafic volcanic rock as asphalt concrete aggregate, granite 1 and diabase as anti-skid aggregates. Dark grey area represents PM_{10} from asphalt concrete, light grey area from anti-skid aggregates. Tests 1 and 2 were performed without sanding. Sanding increased PM_{10} from asphalt concrete: all PM_{10} from asphalt concrete above the white line indicates the abrasive wear of the asphalt concrete by sand grains under the tires (the sandpaper effect). The error bars indicate the error of source contribution.

there are more fine-grained particles the number and surface area of particles increase. Therefore, more particles can grind the asphalt concrete and the sandpaper effect increases.

The properties of the rock used as anti-skid aggregates affected the PM_{10} concentrations too. The aggregate with lowest resistance against fragmentation (granite 1 in Fig. 1; LA value 42/43, see Table 1) caused higher emissions and the effect became more significant when more anti-skid aggregate was dispersed. Diabase resulted in lower PM_{10} concentrations but had a relatively large sandpaper effect.

Fig. 1 showed that sanding greatly increased dust emission. These results were obtained in tests in which mafic volcanic rock was used as asphalt concrete aggregate. In order to study the impact of asphalt concrete aggregate on the generation of airborne PM, granite was used as asphalt concrete aggregate. Fig. 5 shows the comparison of PM_{10} emissions using these two asphalt concretes and diabase anti-skid aggregate. Both rock aggregates have good mechanical properties [27]. Great quantities of PM_{10} were measured in both cases but somewhat (20% on average) more when mafic volcanic rock (A1 in Fig. 1) was

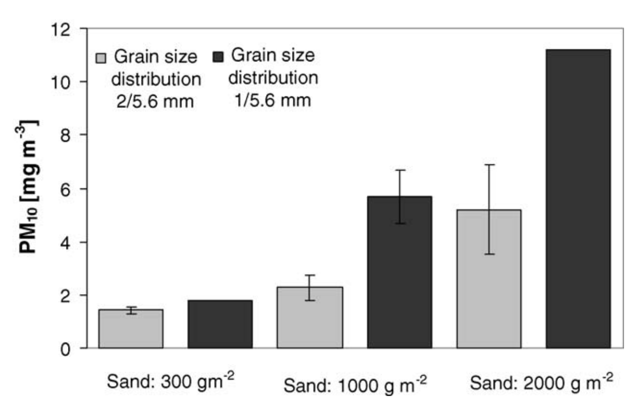

Fig. 4. The impact of the grain size distribution of anti-skid aggregate on PM_{10} concentrations when different amounts of anti-skid aggregate (sand) were used. 1/5.6 and 2/5.6 mm mean 1–5.6 and 2–5.6 mm sized grains.

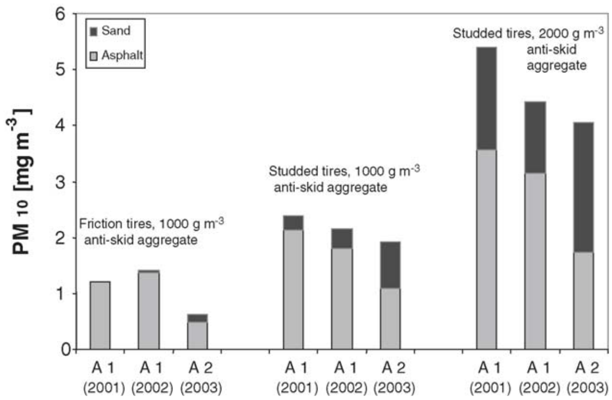

Fig. 5. PM_{10} concentrations generated from anti-skid and asphalt concrete aggregates. Two concretes and diabase as an anti-skid aggregate were used. Asphalt concrete was made out of mafic volcanic rock in A1 (2001 and 2002) and of granite in A2 (2003). Both traction and studded tires and different amounts of anti-skid aggregate (1000 and 2000 g m^{-2}) were used.

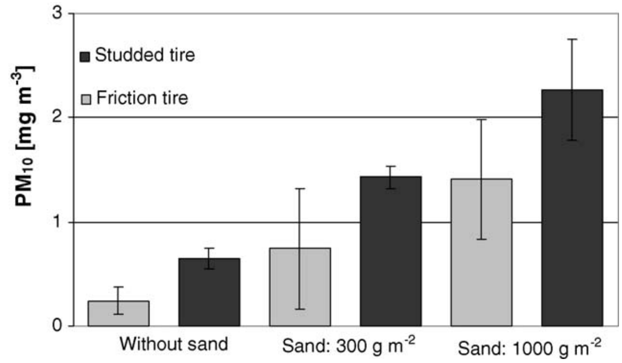

Fig. 6. The impact of tire type on PM_{10} concentrations when different amounts of anti-skid aggregate (sand) were used.

used. The difference was statistically almost significant (Sign test, $p = 0.063$, $n = 4$).

In order to know if there is any difference in the composition of PM when different asphalt concrete aggregates were used, investigations were conducted on the shares of particles originated either from asphalt concrete aggregate or anti-skid aggregates using the same anti-skid material (diabase) and two different asphalt concrete aggregates. The results in Fig. 5 show that the share of PM from asphalt concrete aggregate was relatively lower when granite was used as asphalt concrete aggregate (A2 in Fig. 5). Because the total PM concentrations were also lower with granite, the PM generated from asphalt concrete aggregate was only half (on average) with granite as the aggregate material from that generated with mafic volcanic rock. On the other hand, PM_{10}-dust concentrations generated from diabase anti-skid aggregate were somewhat higher when granite was used as asphalt concrete aggregate. These observations show that the properties of both asphalt concrete and anti-skid aggregate as well as their interaction should be taken into account.

Due to the circular nature of the test ring and low driving speed, abrasive wear dominates over fragmentation. Therefore, relationship between average hardness of asphalt concrete and anti-skid aggregate has a significant importance to aggregate wear. The average hardness of granite anti-skid aggregate is higher than that of mafic volcanic rock aggregate, because granite consists of a higher percentage of hard minerals (quartz and feldspars) compared to mafic volcanic rock. Due to low resistance to fragmentation (high LA-value), granite anti-skid aggregate breaks easily to smaller grains that can wear asphalt concrete made out of mafic volcanic rock that has lower average hardness compared to granite anti-skid aggregate.

3.3. Impacts of tires

The differences in PM_{10}- and $PM_{2.5}$-concentrations between the tires were studied comparing six pairs of measurements from the second set of tests [23]. Statistically significant differences were observed, with higher concentrations when studded tires were used (Sign test, PM_{10} p-value 0.016 and $PM_{2.5}$ p-value 0.031). Similar results were obtained in other test series suggesting that the studded tires increased the PM_{10}-concentrations on average by a factor of 1.5 (Fig. 6).

The results of the carbon measurements made from the second set of tests [23] are shown in Table 2. The average share of the carbonaceous fraction was 5.0% (S.D. 2.0%). It was composed mostly of organic carbon (4.4%, S.D. 1.7%) with trace amounts of elemental (0.2%, S.D. 0.3%) and carbonate carbon (0.4%, S.D. 0.1%). Carbonate-C was present in all tests, which indicated the presence of dust from the limestone powder used in the asphalt concrete filler.

The OC originates either from the asphalt pavement bitumen or from the tires. A statistically significant difference (Sign test, p-value 0.016) was observed with higher mass percentages of OC in the tests with friction tires [23]. This is probably due to the softer rubber of friction tires, which produced more OC than the

Table 2
Results from the OC measurements from the second set of tests for friction and studded tire

	OC (mg m^{-3})		OC (%)		Notes
	Friction	Studded	Friction	Studded	
No anti-skid aggregate	0.04	0.02	8.3	3.0	
No anti-skid aggregate	0.04	0.10	5.7	3.0	30 km h^{-1}
Granite 1	0.15	0.11	5.9	3.9	1000 g m^{-2}
Granite 1	0.18	0.18	4.0	2.8	1000 g m^{-2}, with <2 mm grains
Granite 2	0.09	0.11	6.3	6.2	1000 g m^{-2}
Diabase	0.13	0.09	6.4	3.1	1000 g m^{-2}
Sign test (p-value)	0.656		0.016		

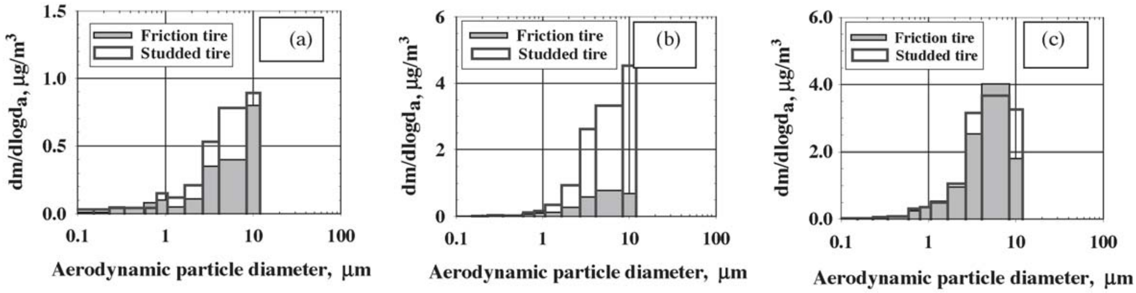

Fig. 7. Size distributions of PM with studded and non-studded tires measured by 12 stage cascade impactor: (a) for 15 km h^{-1} without anti-skid aggregate; (b) for 30 km h^{-1} without anti-skid aggregate; (c) for 15 km h^{-1} with 880 g m^{-2} anti-skid aggregate (figure: modified from Kupiainen et al. [23]).

rubber of studded tires. Friction tires could also release more OC from bitumen than studded tires due to higher friction and heat. On the other hand, there was no significant difference between the two tire types for the mass concentrations of OC (Sign test, p-value 0.656). It was concluded that studded tires produced more suspended particles from the asphalt concrete increasing OC-mass from the bitumen, thus compensating higher tire wear from friction tires and leading to non-significant differences for mass concentrations of OC.

3.4. Size distribution and the composition of fine particles

Mass size distributions of the particles were measured in the second test set and are reported in Kupiainen et al. [23]. The comparison of size distributions in tests with studded and non-studded tires are shown in Fig. 7a for 15 km h^{-1} without anti-skid aggregate, Fig. 7b for 30 km h^{-1} without anti-skid aggregate, and Fig. 7c for 15 km h^{-1} with 880 g m^{-2} anti-skid aggregate [23]. It can be seen that in tests without the sand (Fig. 7a and b), studded tires produce much more particles in the main size classes and are more pronounced with higher speed (Fig. 7b) which is considered to enhance wearing of the asphalt concrete aggregate by tire studs. When anti-skid aggregates were used (Fig. 7c), friction tires produced relatively lot of particles that indicates the importance of the sandpaper effect regardless of the tire type.

The average shares of PM_{10} were approximately 30% of TSP, and shares of $PM_{2.5}$ approximately 12% of PM_{10}. The results from the cascade impactor measurements showed that the submicron fraction ($PM_{0.9}$) was approximately 6% of $PM_{10.7}$ [23]. Particles in the fine and submicron size ranges were present in all measurements. The size distributions are similar to those measured by Chow et al. [42] and Kuhns et al. [43] for paved road dust, Puledda et al. [14] for silica particles, and Silva et al. [44] for soil dust in field conditions. All of these sources are dominated by mineral particles.

A FESEM/EDX analysis of the submicron particles from the fifth and sixth stage of the cascade impactor (50% cut off sizes: 0.45 and 0.69) showed that they were mainly mineral particles from either asphalt concrete or anti-skid aggregates, such as plagioclase, hornblende and quartz [23]. Results show that mineral particles from mechanical abrasion have a measurable contribution especially in the fine mass but also in the submicron mass fraction.

4. Conclusions and recommendations

Experimental results give important information that can be used to evaluate the generation of urban road dust from anti-skid and asphalt concrete aggregates also under field conditions. The use on anti-skid aggregates greatly increases PM_{10} concentrations. However, substantial amount of this increase is caused by the sandpaper effect, i.e. asphalt concrete wear caused by anti-skid aggregate grains between tires and asphalt concrete. This result emphasizes the interaction of tires, anti-skid aggregate, and asphalt concrete in the production of dust emissions. Therefore, they all must be taken into account when measures to reduce road dust are considered.

The amount of anti-skid aggregate dispersed should be minimized. Anti-skid aggregate with fine grain size distribution is not appropriate. The modal composition of the anti-skid aggregate is also important, and aggregates with low resistance to fragmentation are not recommended for their greater dust emissions. Which component is more abraded, asphalt concrete or anti-skid aggregate, depends on the properties of both. Two high quality aggregates were used to produce asphalt concrete. granite was somewhat better than mafic volcanic rock since dust emissions were lower and especially PM from asphalt concrete wear decreased when the same anti-skid aggregate was used. The use of granite in asphalt concrete and diabase as an anti-skid aggregate turned out to be a good combination under these experimental conditions. Studded tires increase PM_{10} concentrations compared with friction tires. However, the use of friction tires produced more organic particles from tire wear that should be noticed.

The winter maintenance measures are also important to prevent springtime dust. Best available technique and combination of practices must be used. Dirty snow must not only be plowed but should be removed frequently from streets. Springtime cleaning must be performed properly with methods that are efficient in reducing PM_{10} dust.

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