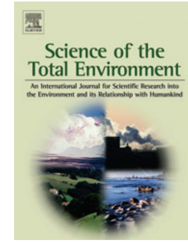
SCIENCE OF THE TOTAL ENVIRONMENT 393 (2008) 226–240

available at www.sciencedirect.com

ScienceDirect

www.elsevier.com/locate/scitotenv



Properties and toxicological effects of particles from the interaction between tyres, road pavement and winter traction material

Mats Gustafsson[a,], Göran Blomqvist[a], Anders Gudmundsson[b], Andreas Dahl[b], Erik Swietlicki[c], Mats Bohgard[b], John Lindbom[d], Anders Ljungman[d]*

[a]Swedish National Road and Transport Research Institute (VTI), SE-581 95 Linköping, Sweden
[b]Division of Ergonomics and Aerosol Technology, Department of Design Sciences, Lund University, P.O. Box 118, SE-221 00 Lund, Sweden
[c]Division of Nuclear Physics, Department of Physics, Lund University, P.O. Box 118, SE-221 00 Lund, Sweden
[d]Faculty of Health Sciences, Department of Molecular and Clinical Medicine, Division of Occupational and Environmental Medicine, SE-581 85 Linköping, Sweden

ARTICLE INFO

Article history:
Received 15 May 2007
Received in revised form
23 November 2007
Accepted 19 December 2007
Available online 6 February 2008

Keywords:
PM_{10}
Particles
Tyres
Traction material
Road simulator
Cell study
Road wear
Traffic emission

ABSTRACT

In regions where studded tyres and traction material are used during winter, e.g. the Nordic countries, northern part of USA, Canada, and Japan, mechanically generated particles from traffic are the main reason for high particle mass concentrations in busy street and road environments. In many Nordic municipalities the European environmental quality standard for inhalable particles (PM_{10}) is exceeded due to these particles. In this study, particles from the wear of studded and studless friction tyres on two pavements and traction sanding were generated using a road simulator. The particles were characterized using particle sizers, Particle Induced X-Ray Emission Analysis and electron microscopy. Cell studies were conducted on particles sampled from the tests with studded tyres and compared with street environment, diesel exhaust and subway PM_{10}, respectively. The results show that in the road simulator, where resuspension is minimized, studded tyres produce tens of times more particles than friction tyres. Chemical analysis of the sampled particles shows that the generated wear particles consist almost entirely of minerals from the pavement stone material, but also that Sulfur is enriched for the submicron particles and that Zink is enriched for friction tyres for all particles sizes. The chemical data can be used for source identification and apportionment in urban aerosol studies. A mode of ultra-fine particles was also present and is hypothesised to originate in the tyres. Further, traction material properties affect PM_{10} emission. The inflammatory potential of the particles from wear of pavements seems to depend on type of pavement and can be at least as potent as diesel exhaust particles. The results imply that there is a need and a good potential to reduce particle emission from pavement wear and winter time road and street operation by adjusting both studded tyre use as well as pavement and traction material properties.

1. Introduction

Numerous studies have shown that the concentration of inhalable particles (PM_{10}) in ambient air is associated with mortality and different kinds of respiratory health problems in the population (Katsouyanni et al., 2001; Peters et al., 2001; Brunekreef and Holgate, 2002; Pekkanen et al., 2002; Pope et al., 2002; Hoek et al., 2002; Kappos et al., 2004). Particle size seems

* *Corresponding author*. Tel.: +46 13204326; fax: +46 13141436.
E-mail address: mats.gustafsson@vti.se (M. Gustafsson).

0048-9697/$ – see front matter
doi:10.1016/j.scitotenv.2007.12.030

to be important since smaller fractions tend to have stronger relationships to health effects (Schlesinger et al., 2006). However, meta-analysis of epidemiological studies differing between the coarser particle mode $PM_{10–2.5}$ and the finer $PM_{2.5}$, shows that there seem to be health effects from both fractions (Brunekreef and Forsberg, 2005). The coarser mode seems more related to acute airway symptoms while the finer mode seems more related to cardiovascular disease. However, not only the numbers of PM are of importance for health effects, but also the qualitative properties of the particles determine the ability to induce inflammation (Øvrevik et al., 2004) This includes the size, shape, chemical composition, physical properties, material absorbed or adsorbed to the particles that may depend on several factors of which the season is one as different toxicological properties have been noted between spring and winter PM (Salonen et al., 2004). The mechanisms and properties that make particles more or less toxic are poorly understood though. To find optimal measures against high particle concentrations in public areas, it is important to study source specific particle characteristics as well as to determine what properties of the parent material are important for the release of inhalable wear particles.

Since the early eighties it has become increasingly evident that wear particles from road pavements and tyres strongly contribute to episodes with very high concentrations of inhalable particles in outdoor air (Amemiya et al., 1984; Fukuzaki et al., 1986; Hosiokangas et al., 2004; Swietlicki et al., 2004). These episodes normally occur during dry periods in winter and spring. During the winter season in Sweden, about 70% of light duty vehicles use studded tyres, ranging from about 40% in the southernmost parts to over 90% in the north. Even though pavements have been improved since the 1980s and studs nowadays are mainly made of lightweight alloys instead of steel, about 100 000 tons of pavement is worn each winter season in Sweden (Jacobson, 1999). Although most of the particle mass of the wear particles is from particles that are far larger than 10 μm, a minor airborne inhalable fraction is generated and contributes to the air pollution in the road environment and might also contribute to long range transport. Also, winter sanding in urban areas contributes to dust formation, both through vehicles grinding the sand, but also through increased pavement wear by sand. In Finland a similar road simulator as in the present study, has been used to study wear particle production from tyres, pavements and winter traction material (Kupiainen et al., 2003, 2005; Räisänen et al., 2003, 2005; Tervahattu et al., 2006). Their most important results show that studded tyres produce more PM_{10} than non-studded tyres, that stone material properties for both pavement and traction sand are important for particle production and that traction sand act as a sand paper on the pavement regardless of which tyre type is used.

During dry periods in winter and early spring, abraded pavement and sand are ejected into the air by vehicle turbulence and cause particle concentrations to vastly exceed the environmental quality standard set for inhalable particles (Johansson et al., 2007). This standard is valid for PM_{10} and stipulates that the daily mean concentration must not exceed 50 $\mu g\ m^{-3}$ more than 35 days a year and the yearly mean must not exceed 40 $\mu g\ m^{-3}$ (EU, 1999).

The road dust problem is an issue not only in countries using studded tyres and traction sanding. Even though the problem is not as obvious, pavements as well as tyres are worn by traffic globally and produce potentially hazardous inhalable particles. In many countries, including EU-countries and the USA, non-exhaust particles are considered an important research field due to the lack of knowledge and the complex formation and emission processes. Also, as particle contribution from vehicle exhaust is abated, the relative contribution from non-exhaust particles is increasing (Luhana et al., 2004).

The aim of this study was to characterize wear particles and to study their possible health effects. Using a road simulator in a laboratory hall, it was possible to exclusively measure and characterize the generated airborne wear particles from two common Swedish pavements worn with studded tyres and to study the inflammatory potential of the particles in human macrophages and epithelial cells. Also wear particles produced using Nordic friction tyres as well as two types of traction sand were studied. This paper presents the main results from the particle characterization and the cell studies.

2. Methods

2.1. *Particle generation and characterization*

2.1.1. *Generation of wear particles*

A road simulator (Fig. 1) (Swedish National Road and Transport Research Institute, Linköping) was used to generate wear particles from studded and friction tyres running on two different pavements. Particle sampling in the simulator hall ($10\times8\times5$ m^3) makes it possible to sample wear particles with very low contamination from surrounding sources and no influence from tail-pipe emissions. Apart from the lack of other particle sources than pavement and tyres, the simulator also has the advantage of providing the possibility to minimize the contribution from resuspension of dust not directly related to the pavement and tyres studied, which can be an important contribution and problem during field campaigns. Thorough cleaning of the entire simulator hall before each test minimizes resuspension from old dust originating in previous tests. The intense movement of the tyres over the pavement does not allow for deposition on the track, also contributing to minimized resuspension of newly produced dust.

The simulator consists of four wheels running a circular track with a diameter of 5.3 m. A DC motor is driving each wheel and the speed can be varied up to 70 km h^{-1}. At 50 km h^{-1} a radial movement of the wheels is started to force the tyres to wear evenly on the pavement. The simulator track can be equipped with any type of pavement and any type of tyre can be mounted on the axles. No forced ventilation of the simulator hall was used, but pressure gradients might have caused minor self-ventilation.

It should be kept in mind though, that the laboratory conditions at the simulator are not directly comparable to reality in terms of absolute concentrations. The tight turn, 100% studded tyres, dry conditions, constant speed without accelerations and decelerations and small air volume all add to the non-realistic conditions. The tight turn of the wheels causes pavements to wear approximately 3–4 times faster than on roads, even though