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AIRBORNE WEAR PARTICLES FROM AUTOMOTIVE BRAKE SYSTEMS IN URBAN AND RURAL AREAS

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Abstract: Non-exhaust vehicle emissions are currently thought to be tyre wear, brake wear, clutch wear, road surface wear, corrosion of other vehicle components, corrosion of street furniture and crash barriers, and the resuspension of road dust. Among non-exhaust sources, brake wear can be a significant particulate matter (PM) contributor, particularly within areas with high traffic density and braking frequency. Regulations for brake pad performance are influenced by many bodies across the world, including the Particle Measurement Programme by the United Nations Economic Commission for Europe (UNECEPMP). In order to continuously improve their products and ensure regulatory compliance, brake pad manufacturers conduct brake performance tests and they can be carried out on vehicles and on dynamometers. The main topic of this paper regards the potential impact of the emitted PM on the human health, depending on the mechanisms of formation and toxicity of the particles. On-going European projects dealing with this important problem will also be discussed in the paper.
Keywords: Brake system; wear particles; legal requirements; health

INTRODUCTION

The pollutants present in the ambient air, primarily respirable particles (particulate matter-PM), draw a lot of attention of researchers, regulatory bodies and the general public because of its negative effects on human health. The legislation of the European Union for many years, and since 2010 also the Serbian regulations, prescribe monitoring of two fractions of particles present in the air, with aerodynamic diameter less than 2.5 μm, so-called fine particles, and smaller than 10 μm, PM_{10}, which includes fine particles and the coarse particles that are in the range of 2.5-10 μm. In addition to natural sources, the most important anthropogenic air pollution sources include power plants and traffic. Fine particles and gases from power plants and transport often come from the combustion process. The literature indicates that industrial processes are the biggest sources of pollution, followed by emissions from installations for the collective and local heating and all forms of transport that represents the process of burning fossil fuels that are not directly ties with industry. In urban areas, road traffic is marked as the biggest source of air pollution [1].

The particulate matter generated by road transport activity can be categorised according to its mechanism of formation. It is often assumed that diesel exhaust is the main source of particulate matter from road vehicles. However, there are a number of non-exhaust processes which can also result in particulate matter being released directly to the atmosphere. The main abrasion processes leading to the direct emission of particulate matter are tyre wear, brake wear and road surface wear. In addition to direct non-exhaust emissions, material previously deposited on the road surface can be suspended or resuspended in the atmosphere as a result of tyre shear, vehicle-generated turbulence, and the action of the wind. In the case of road transport, it is commonly assumed that most primary fine particles ($PM_{2.5}$) are emitted from the exhaust, whereas many of the coarse particles (PM2.5-10) are considered to originate from non-exhaust sources. This over-simplifies the situation somewhat; there is evidence to suggest that non-exhaust particles contribute to both the fine and coarse modes [2].

The composition of the friction material influences the brake wear factor. The three types of brake lining tend to be used for conventional applications. NAO linings are relatively soft and create less noise, but they generally wear faster and create more dust than the other types. Low-metallic linings are made from an organic formula mixed with small amounts (10 to 30 %) of metal to help with heat transfer and provide better braking. With the added metal, there is more brake dust, and they may be slightly noisier. Semi-metallic linings have a metal content of around 30 to 65%. These pads are more durable and have excellent heat transfer, but also wear down rotors faster, have intrusive noise characteristics, and may not perform as well under low-temperature conditions [3].

Driving behaviour, in particular the frequency and severity of braking events, is also an important determinant of brake wear. Because the brake wear only occurs during forced decelerations, the highest concentrations of brake wear particles should be observed near busy junctions, traffic lights, pedestrian crossings, and corners. However, particles may also be released from the brake mechanism or wheel housing sometime after the primary emission event [2].

The aim of the present study is to present the different aspects regarding PM resulting from brake wear and provide all the necessary information in terms of physicochemical characteristics, emission factors and possible adverse health effects. On-going European projects dealing with this important problem will also be presented.

BRAKE WEAR PARTICLES

The results of the recently published study conducted in three European countries, Austria, Switzerland and Germany where 75 million people live, estimated that exposure to respirable particles responsible for about 40,000 deaths per year. Half the number of these deaths is attributed to particles from traffic, which is equal to the number of people who annually die in the European Union in traffic accidents. The introduction of limit values of concentrations of pollutants in the ambient air, in particular, those relating to respirable particles, contributes to improve the health of populations, which certainly has positive economic effects too [4].

Respirable particles are characterized by a number of characteristics including size, density, shape and composition. Generally, the impact on human health, effects on the environment and the fate of particles depend on their size. Particulate matter is frequently classified according to its size, i.e. PM_{10}, $PM_{2.5}$ and $PM_{0.1}$ for particulates with an aerodynamic diameter D smaller than, respectively, 10 µm, 2.5 µm and 0.1 µm. Very coarse particles (D>10 µm) are generally filtered in the nose and throat. Coarse particles (2.5 µm<D<10 µm) can settle in the bronchi and lungs. Fine particles (0.1 µm<D<2,5 µm) can easily penetrate into the lungs gas exchange regions, and they might cause vascular inflammation related diseases and possibly lung cancer. Ultrafine particles (D<0.1 µm) or nanoparticles might be even more dangerous, as they can reach intimate structure of tissues and organs and act as nucleations sites for cancer and degenerative pathologies.

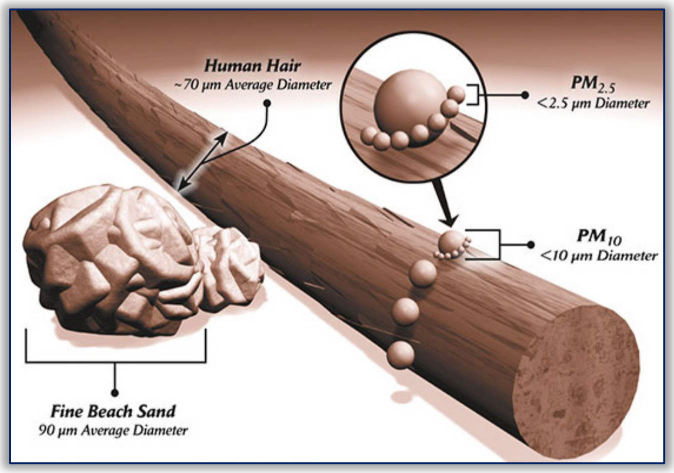

Figure 1. Relative Size of Particulate Matter

Despite the emissions of $PM_{2.5}$ and PM_{10} decreased by 16% and 21% respectively between 1999 and 2009, PM limits were exceeded widely across the EU area, a quite discouraging result. Whilst exhaust gases in the road transport are monitored and are the object of the European directives, less is known about the particulates originating from the wear of e.g. brakes and tyres. A recent study for the city of London regarding 2011 and 2015 PM emissions, estimated a consistent increase of the PM wear emissions (brakes and tyres) with respect to the overall PM emissions: from 35% to 47% for PM_{10} and from 40% to 55% for $PM_{2.5}$.

During rapid deceleration, brakes are subject to large frictional heat generation, which leads to the wear of linings and disc. Brake wear emissions tend to occur at junctions, traffic lights, corners and other sites where rapid deceleration occurs. For light-duty vehicles (LDV) and heavy-duty vehicles (HDV), total brake wear factors are around 10-20 mg/vkm and 50-80 mg/vkm (vehicles kilometres) respectively. Around 50% of the particles generated normally enter the atmosphere, and 80% of the emission appears to be PM_{10}.The proportion originating from the wear of the brake linings compared with wear of the disc or drum is uncertain [2].

EUROPEAN PROJECTS RELATING TO EMISSION OF BRAKE WEAR PARTICLES

Compliance with air quality standards for PM_{10} requires control of both fine and coarse particles. As the two modes tend to have different sources and formation mechanisms, different types of control are required. Primary fine particles from combustion sources are subject to regulation. As a result of the changes in legislation, and following the development and application of new technologies, the mass concentration of particles in the exhaust of diesel engines has reduced steadily over the last 20 years. There are currently no legal requirements for the control of the road vehicle non-exhaust particle emissions in the EU. Certain regulations, which are designed for other purposes, could influence nonexhaust PM emissions indirectly. Such regulations include restrictions on the use of studded tyres in certain countries to reduce damage to the road surface, and road/tyre noise standards [2]. There are several on-going research projects, some funded by the EU (e.g. REBRAKE) some by other organizations, that address different issues and very often are not known outside the involved groups or organizations.

Rebrake's project twofold objectives aim at on the one hand bringing a deeper comprehension of the physical and chemical phenomena underlying the brake wear process, including higher comprehension and analysis of characteristics coarse, fine and ultra-fine particles (UFP) and on the other of reducing at least 50% particulate matter (PM_{10}) from brake wear, in compliance with the EU2020 thematic strategy of 47% reduction of particulate matter by 2020. The Rebrake project is articulated in four phases. In the first phase of the project, the experimental brake tests consist in setting up experimental tests and elaborating PM collection methodologies. In the second phase, the collected particles, from conventional and, newly developed materials, are chemically and morphologically characterized and compared with literature results regarding human health impacts. In the third phase of the project wear mechanisms are modeled and correlated to the actual brake system parameters and to the ingredients of the linings under investigation. In the fourth phase, novel brake systems will be engineered, in order to cut down the PM emissions by 50%. Knowing the influencing factors on brake dust emissions and how to measure the impact of changed parameters, it is possible systematically to search for measures to reduce the particle emission e.g.

change in formulation, collect the particles or change their physical properties in a way that makes then less harmful [5].

The LOWBRASYS project aims at demonstrating a novel and low environmental impact brake system that will reduce micro and nanoparticles emissions by at least 50%. The measurement and understanding of micrometer-sized and ultrafine particles and their effects on health and the environment will be improved and whilst providing recommendations to policy makers. The LOWBRASYS challenge is to develop a new generation of transport technologies able to push innovation towards a cleaner and more efficient road transport, improving air quality with positive effects on both environment and human life. At the same time LOWBRASYS matches the requirement to comply with possible future stricter legislations on vehicles emissions (both exhaust and non-exhaust) and EU air quality [6].

COBRA will demonstrate a completely novel brake pad production technology that will be based on an innovative hydraulic binder composition instead of phenolic resins, at comparable braking performance. State-of-the-art brake pads are constituted by thermo setting phenolic resins, which are suitable for friction and relatively high contact temperature applications. In addition, the novel technology will avoid the emission of aerosols and secondary ultrafine particulate ($PM_{0.1}$) generated during braking by traditional phenolic-resin-made pads.

Since the phase out of asbestos brakes, brake lining material contains 1–14% Cu with an average Cu content of 5–10% in current brake linings. This makes brake wear from vehicles an important source of atmospheric copper concentrations. It is the dominating source of copper in ambient air in Western Europe. The history of changing regulations governing chemical compounds used in automotive brake pads in North America is shown in Figure 2 [7]. In March 2010, Washington became the first state to pass legislation in an effort to protect its waterways from the runoff of toxic copper brake dust. California also passed a bill, which became law in September 2010. The California law mandates that brakes contain no more than 5 percent copper beginning in 2021. By 2025, the limit will be reduced to 0.5 percent.

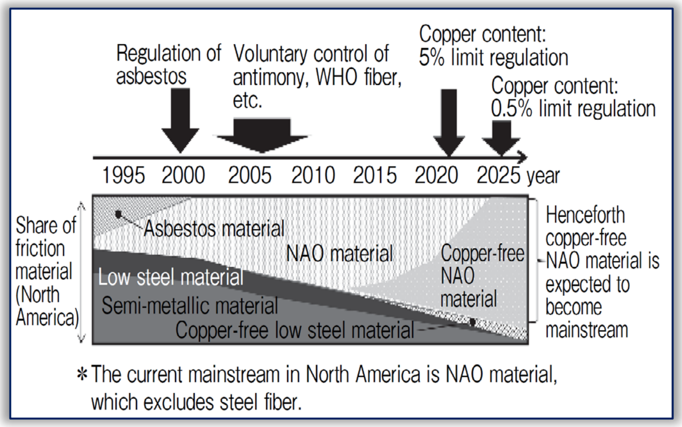

Figure 2. Change in the Regulation of Chemical Substances for Brake Pads [7]

DEVELOPMENT OF A STANDARDIZED METHOD FOR MEASURING BRAKE WEAR PARTICLES

All involved parties agree that a standardized test procedure for sampling and investigating brake wear particles, both in terms of mass and number, would be beneficial for the research and the development of low emitting brake systems. Brake wear particles generation and sampling can be performed in the laboratory by means of a roller chassis bench (Full Chassis Dynamometer), a brake dynamometer or a pin-on-disc configuration. In one case the attention is focused on particles generated at brake system level while in the other case at vehicle level. While measuring brake particle emissions from a whole vehicle would better reflect real world conditions and would enlarge the range of possible technologies for particle emission reduction (vehicle-to-vehicle communication, hybridization, etc.), this represents a very complex challenge from a scientific and technical point of view. Issues like the representativeness of sampled particles and contribution from other sources (tyres, road, exhaust gas) appear very difficult to resolve.

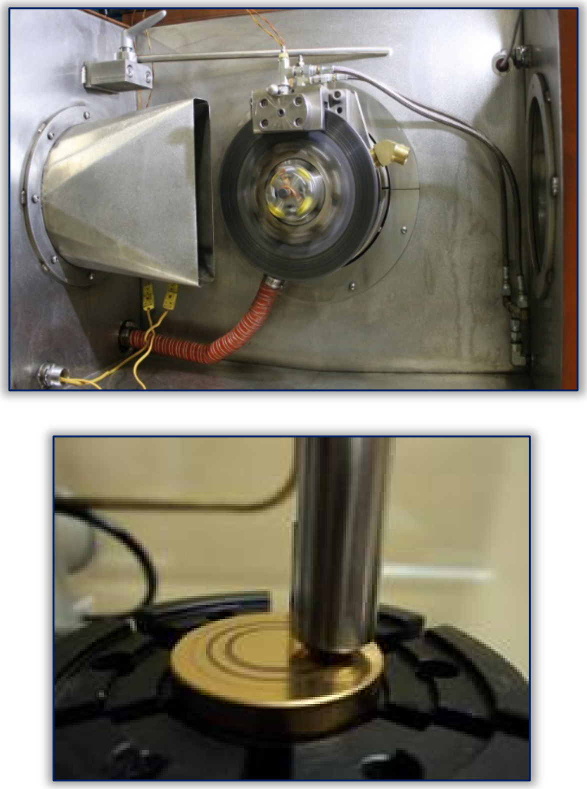

Figure 3. Measuring of brake particles

Test rigs are considered a much simpler solution to investigate particle emissions from brake systems. Brake system suppliers as well as instrument manufacturers is actively working on the development of test rigs based on a brake dynamometer to generate, sample, and characterize particles.

CONCLUSIONS

Even though a hazardous effect of emissions from friction brakes on humans has not been proven, future regulations are expected to cover total vehicle emissions including those from friction brakes. Overall brake emissions are highly depending on the applied drive cycles and braking conditions. The quantitative measurement of brake emissions is difficult and complex as the observed system around the brakes has no defined boundaries and cannot be closed without interfering with the particle flow and influencing the measuring results. It is predicted that the relative contribution of non-exhaust sources to traffic related emissions will increase in the forthcoming years due to stricter control in exhaust emissions.

Acknowledgment:
Research presented in this paper was supported by Ministry of Education, Science and Technology Development of the Republic of Serbia, Grant TR 35041.

Note:
This paper is based on the paper presented at 13th International Conference on Accomplishments in Mechanical and Industrial Engineering – DEMI 2017, organized by University of Banja Luka, Faculty of Mechanical Engineering, in Banja Luka, BOSNIA & HERZEGOVINA, 26 - 27 May 2017.

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ACTA TECHNICA CORVINIENSIS BULLETIN OF ENGINEERING
ISSN: 2067-3809