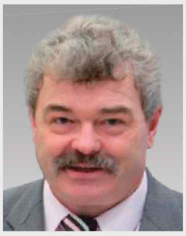
Guest Forum

Investigation of Brake Wear Particles



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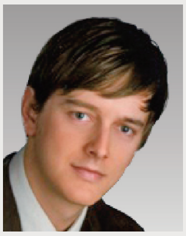

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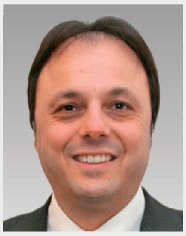

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Over the last years, brake dust has become a topic in different fields. The first research to brake dust after the abolishment of asbestos was done to understand the staining of the wheel. Since then, several attempts were made to understand the synthesis, composition and distribution of brake dust because of the growing awareness of environmental and health effects, for example with antimony and copper in the brake pads. The published measurements for the number and size of brake particles vary widely.[1-5] This is mainly because of the complex and susceptible characteristics of a brake system and the limited resolution of many measurement systems. With every change in temperature, braking speed, braking pressure, pad formulation, brake type and history of the friction partner, differences in the properties of brake dust particles will be recognizable. One approach to measure the size of the particles is to analyze a sample of collected brake dust in a scanning electron microscope. The handicap of this method is the characteristic of the debris to agglomerate and to deposit dependent on the particle size. A precise analysis of airborne particulate matter requires a more complex methodology which is known from the combustion engine particle measurement. HORIBA offers equipment to detect the particle size from ~2 nm up to 600 nm, for example the MEXA-2100SPCS*1 with a DMA*2 3081 classifier and a CPC*3 3776.

過去数年間に渡り，ブレーキダストは様々な分野で話題になっている。アスベストの使用廃止後，ブレーキダストの最初の研究はホイールを汚すことを理解するためであった。その時以降，例えばブレーキパッドのアンチモンと銅のような元素の環境，健康に対する影響への意識が高まり，ブレーキダストの合成，組成，および分散について理解するためにいくつかの試みが行われた。ブレーキ摩擦微粒子の数とサイズについて公表された測定値は非常にばらつきが大きい[1-5]。これは主としてブレーキシステムの複雑な動作条件と多くの測定装置での限定された分解能等の分析性能による。温度，ブレーキ速度，ブレーキ圧，パッド配合，ブレーキタイプ，および摩耗ペアの履歴が変化するたびに，ブレーキダストの特性の違いが見られる。微粒子のサイズの計測の1つの方法は，集められたブレーキダストの試料を走査型電子顕微鏡で分析することである。この方法の不利な点は，ダストが凝集し易い事と粒径により堆積する事が挙げられる。空中に浮遊する粒状物質の正確な分析には，燃焼機関の粒子測定で知られる，より複雑な方法が必要である。HORIBAは約2 nmから600 nmの粒子サイズまでを測定できる，例えばDMA*23081およびCPC*33776装置と共に用いるMexa-2100SPCS*1といった測定装置を提供している。

*1: Solid Particle Counter System（固形粒子数計測システム）
*2: Differential Mobility Analyzer（微分型移動度分析装置）
*3: Condensation Particle Counter（凝縮粒子カウンター）

Introduction

Beside combustion particles the wheel brake is the main emitter of nano-sized particles of passenger cars. The environmental problems of brake dust were reviewed in previous scientific works, e.g. “Method for visualization and handling of brake dust emissions” by Audi AG and TU Ilmenau, chassis.tech 2010 and “Brake dust measurement” by HORIBA Europe and TU Ilmenau at the Eurobrake 2012. Especially copper is known to harm the environment. Therefore the State of California introduced a law for the ban of copper in brake pads. Several papers proved a wide size distribution from a few nanometers to few micrometers. Another key fact to understand the effects of brake dust is the material composition of the emitted particles. The friction system of a brake is a complex structure which contains more than a dozen substances. With a combination of different measurement techniques the emissions can be characterized on a brake dynamometer. Brake dust from the surface of a wheel has been analyzed by SEM*4-EDX*5 to find out the physical properties and the chemical structure. Properties of the particles vary widely dependent on the braking temperature, rotating speed, braking pressure and the friction partners.

*4: Scanning Electron Microscope
*5: Energy Dispersive X-ray Spectroscopy

Scanning Electron Microscope

A quick method to measure the size of the particles is to generate images of collected brake dust in a scanning electron microscope. A drawback of this method is the characteristic of the debris to agglomerate and to deposit dependent on the particle size and their electric charge. If a sample of brake dust is collected on a sample holder it will never exactly have the size distribution of the airborne particles behind the brake caliper. Differences can also be demonstrated in the particle mass which is deposited on a wheel fixed to a brake dynamometer setup and a wheel which lies next to the brake setup. This shows the effect of the electric charge.

This airborne fraction can be measured with available particle counters and particle size measuring devices. This equipment is often based on the light dispersion of laser light through the particles. Tests on a brake dynamometer were successful as the results were repeatable and it was detectable, that brake emissions increase exponentially with braking energy. The particle size and the number of particles for brake emissions show similar behavior compared to the emission of combustion engines. An additional parameter for the brake system is the substantial composition of the brake dust, considering that the material of a brake pad can contain a wide range of substances. An analysis with SEM-EDX shows the distribution of elements in the brake debris, while there is still no possibility to detect the accurate molecular formation. EDX showed an equal composition of the brake dust to the brake pads, only with a higher amount of iron, coming from the brake disc. The main ingredients of brake pads are e.g. iron, copper, silicon, aluminum, manganese and others. The exact chemical bond was also examined by XRD[*6], which can detect crystallographic materials. The outcome was a distribution with high rates of iron oxides, graphite, silicon oxide, copper, potassium oxide and corundum. In their different chemical compounds these ingredients are converted to micro and nanoparticles. In an accumulation process after the generation, particles tend to adhere together. The result is a mixture of all brake dust ingredients to small clustered particles. Current research aims towards an understanding of the exact composition of brake wear particles and their effects on mechanical components and human health.

The particle size and amount of particles depend on several factors, mostly the rotational speed of the disc and the applied brake pressure. First, the particle size was measured optically by collecting brake dust on a wheel surface and using a SEM subsequently. It was possible to compare several brake scenarios by the amount of brake dust on the surface as well as the method offered an estimation of the particle size. (Figure 1)

*6: X-Ray Diffraction

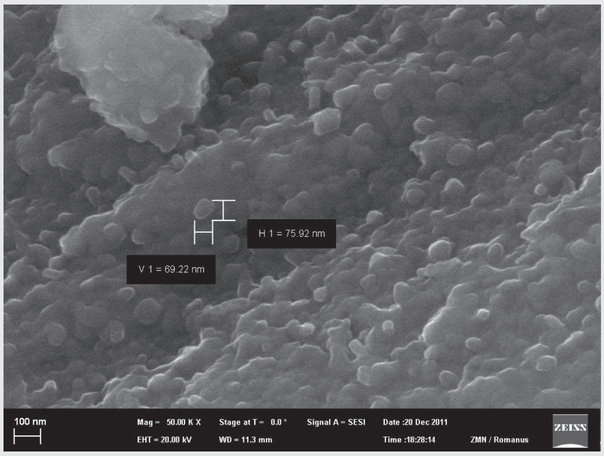

Figure 1 SEM Image of collected Brake Dust

HORIBA Solid Particle Counter System

Previous investigations with the SEM showed that simple systems for particle detection would not be sufficient to characterize the amount and size distribution of brake dust.

The brake dust can be collected with a HORIBA SPCS directly after the caliper and goes through a heated tube to the analyzer unit. (Figure 2, Figure 3) Result is a reliable size distribution for airborne brake dust particles. A drawback to the results is the minimal measurement time of 120 seconds for correct results. This requires a

Figure 2 HORIBA SPCS

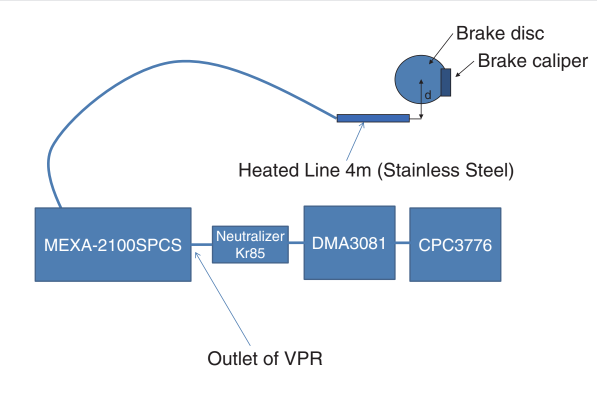

Figure 3 Schematic Measurement setup SMPS*7

long brake-on time in drag mode to generate a constant particle flow which is limited representative for a usual braking scenario. A difficulty for particle size measurement is the complex behavior of the debris. It runs through several processes, in which the particles agglomerate and condensate:

Emission → Transport → Transformation → Immission → Deposition[8]

This is what makes it complicated to get reliable numbers for a size distribution. The analysis with the HORIBA SMPS (Figure 4) showed that brake dust particles appear in a size range similar to diesel engine exhaust. So the size range of diesel particles will mostly be covered by the wider size range of the brake wear particles except for the smallest diesel fraction. (Figure 5) The measurements took place on a brake dynamometer at different speeds, brake pressures and cooling air speeds. In previous measurements with CPCs it was shown that the amount of particles is strongly connected to the braking energy. Compared to a highway braking scenario with a deceleration of 0.4 g and a change in speed of 150 km/h to 80 km/h, a city braking scenario with 0.25 g from 50 km/h to zero generates less than 5% of the brake wear debris weight.

For future measurements, smaller size measurement ranges would allow shorter brake activation and also higher brake pressure. These experiments with specific measurement systems have already showed that the airborne particle size is smaller than the assumed sizes from the research with scanning electron microscope. There were also previous attempts for measuring the particle size with specialized devices like ELPI*8 oder MOUDI*9 impactors. This research was done by Paul Sanders at Ford Motor Co. In his publications he describes size and mass measurements of brake wear particles from different pad qualities. One of his conclusions is particle number peaks for a size under 1 µm.[6], [7]

*7: Scanning Mobility Particle Sizer
*8: Electrical Low Pressure Impactor
*9: Micro-Orifice Uniform Deposit Impactor

Particle Image Velocimetry

A Particle Image Velocimetry (PIV) system is used to visualize the particulate matter. This allows a snapshot view of the emitted particle during the on-brake scenario. This offers an impression of the amount of emitted particles and how they move. PIV requires at least one camera and a triggered laser which produces a highlighted area in the image plane of the camera. The strong laser light allows short exposure times for the camera, which is required to take a picture of fast moving particles.

The particle mass emitted during a braking scenario can be evaluated with the PIV and digital image processing. This information is helpful for particle measurement as it

Figure 4 SMPS System with DMA and CPC

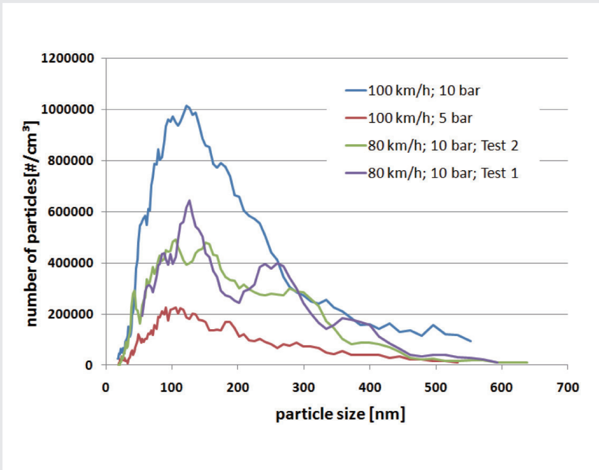

Figure 5 Size Distribution of Wear Particles

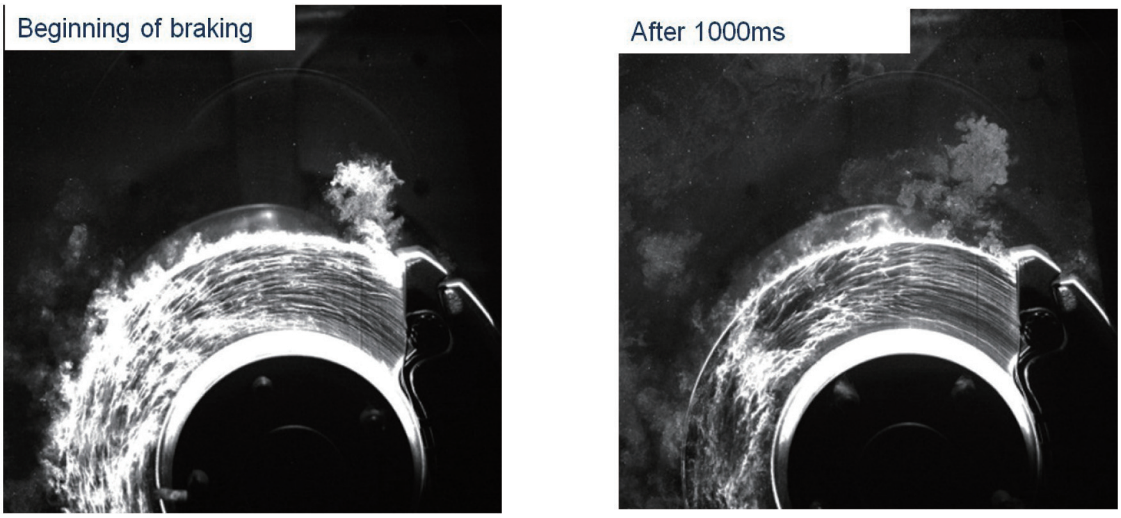

Figure 6 Particles around disc brake with laser sectioning method from PIV

will show where the probe tube of the SPCS has to be installed near the brake. (Figure 6)

CONCLUSION

With a combination of measurement techniques, the emissions of a friction brake were characterized on a brake dynamometer. Several previous publications proved a wide size distribution from a few nanometers to a few micrometers. Measurements with a HORIBA SMPS demonstrated that if a Gaussian distribution is assumed, the peak of the size distribution is below 250 nm. This is still larger than diesel exhaust particles but there is nevertheless a certain fraction of ultrafine particles. Simpler measurement systems mostly detect only particles larger than 300 nm so the main fraction of brake particles is not taken into account.

The friction system of a brake is a complex structure which contains more than a dozen substances. Properties of the particles vary widely and depend on the brake temperature, braking power and friction partners.

For future measurements there is room for improvement regarding the measuring time. To measure the size distribution with a SMPS takes usually more time than a single braking process. A drag braking setup was used for the present size distributions, so the rotational speed and the pressure were kept constant. This does not completely match with the properties of a real driving cycle braking scenario.

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