Brake dust emission

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15th ETH-Conference on Combustion Generated Nanoparticles, June 26th – 29th 2011

Session 7: Non Engine Emissions

ABSTRACT

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. Especially copper is known to harm the environment. Therefore the State of California introduced a law for the ban of copper in brake pads.

With a combination of different measurement techniques the emissions were characterized on a brake dynamometer. Brake dust from the surface of a wheel was analyzed by SEM-EDX and XRD to find out the physical properties and the chemical structure. Several papers proved a wide size distribution from a few nanometers to few micrometers. If a Gaussian distribution is assumed the peak of the size distribution is below 250nm. 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. Properties of the particles vary widely dependant on the braking temperature, rotating speed, braking pressure and the friction partners.

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 examined by XRD, 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 chemicals 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. Therefore, tribological behavior was studied on a special brake test for the characterization of particle generation process. A setup with a transparent brake disc and a high-speed camera was used to visualize the friction zone.

INTRODUCTION AND FUNDAMENTALS

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 brought at least the distribution of atoms in the brake debris, while there is still no possibility to detect the accurate molecular formation.

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.

SIZE DISTRIBUTION

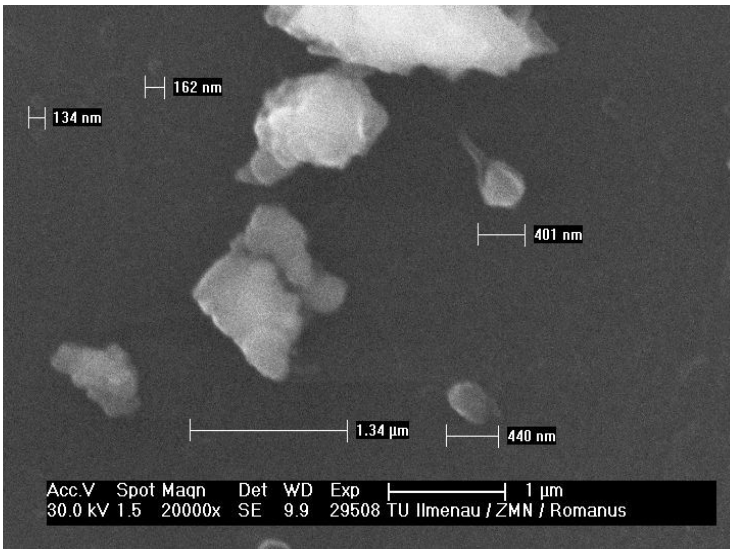

Figure 1: Particle size measured with SEM Philips XL30

Figure 1 shows brake dust particles on a wheel surface. A section of the wheel was taken off after the test cycle on the brake dynamometer. Particle sizes from more than 100nm to 20µm were detected. A precise analysis of airborne particulate matter required a more complex methodology. HORIBA offers equipment to measure the particle size from ~2nm up to 600nm: the Mexa-2100SPCS with a DMA 3081 classifier and a CPC 3776.

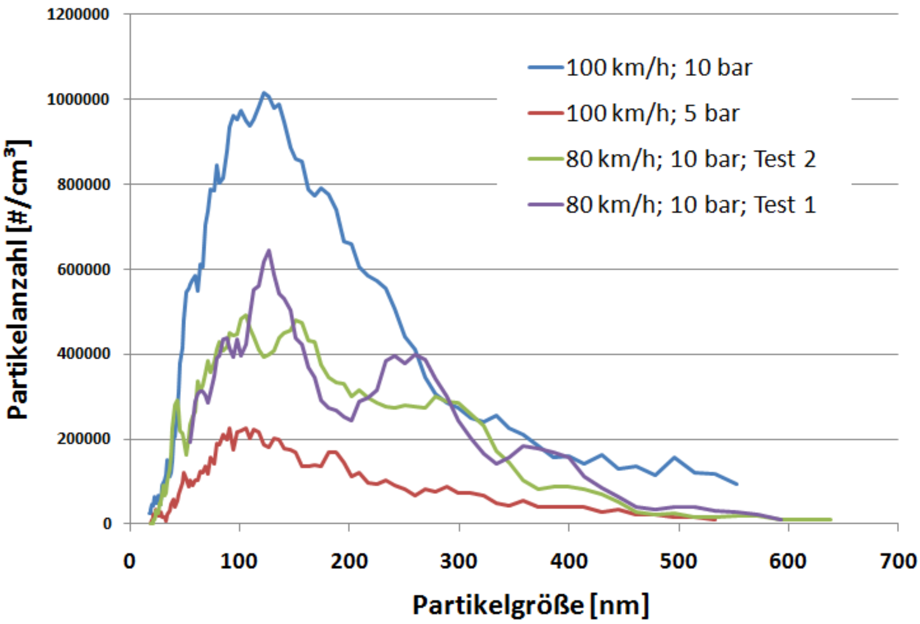

Figure 2: Size distribution for drag braking, measured with HORIBA Mexa-2100SPCS

The analysis showed that brake dust particles appear in a size range similar to diesel engine exhaust, even if the peaks of the distribution are in a ten times higher range. The size distribution was measured during several braking scenarios at different speeds, brake pressures and cooling air speeds. In previous measurements with CPCs it was shown that the amount of particles is linked to the brake energy. High energy scenarios with 150km/h initial speed for example were measured with a 25-times higher particle concentration than low energy brake scenarios with 50km/h.

MATERIAL COMPOSITION

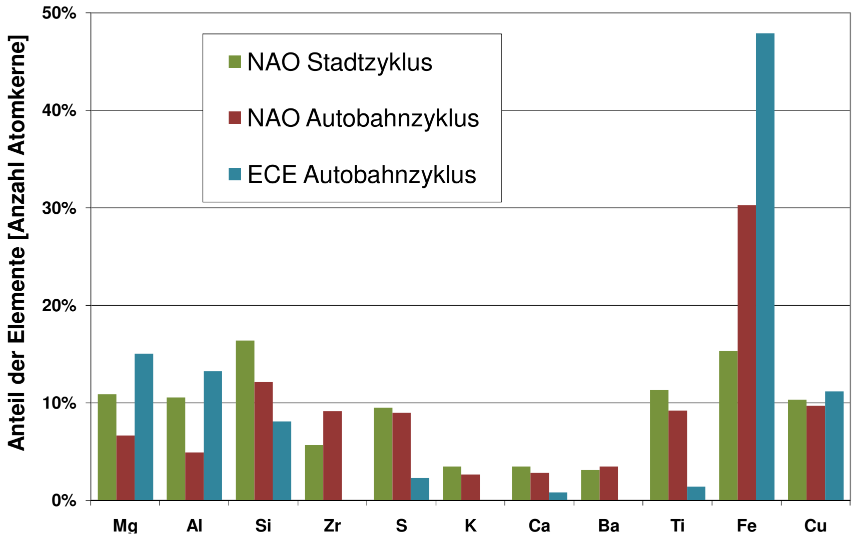

Figure 3: Distribution of elements of brake dust measured with SEM-EDX

SEM-EDX shows in dependency of the brake scenario and brake pad type that the same brake can produce different compositions of brake dust. The brake pad formulations depend on the country specific manners of driving and the vehicle type. In Europe, mostly with higher speed limits than in the Asian or American regions, the preferred pad formulation is the low-metallic type, also called ECE. These brake pads offer a high friction level, which results in a higher amount of debris, especially iron coming from the brake disc. Iron is not regarded to be harmful to the environment. In contrast, copper is an example for a highly harmful element, which is still not banned in brake pads contrary to asbestos, lead, mercury, cadmium or chromium.

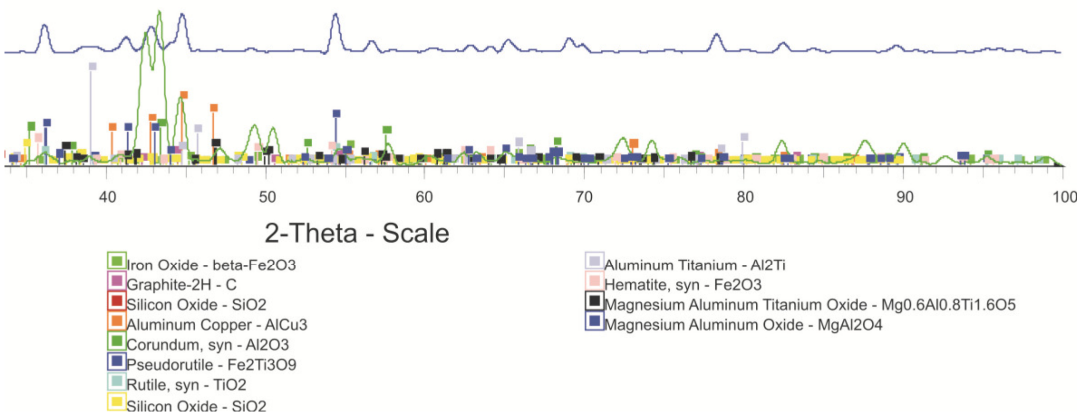

Figure 4: Excerpt from a XRD analysis

With an internal x-ray diffraction (XRD) it is possible to detect crystalloid molecules in the dust. This gives an important hint for the detailed composition of the dust since the brake pad manufactures don't publish their formulations. And even with the knowledge of the ingredients in a braking scenario with temperatures from 300°C by normal driving to 600°C and above with hard driving the chemical transformation processes can produce different materials than the initial formulation contains. XRD shows a wide range of crystalloid materials in the brake dust. Some of them are known to be contained by brand new brake pads.

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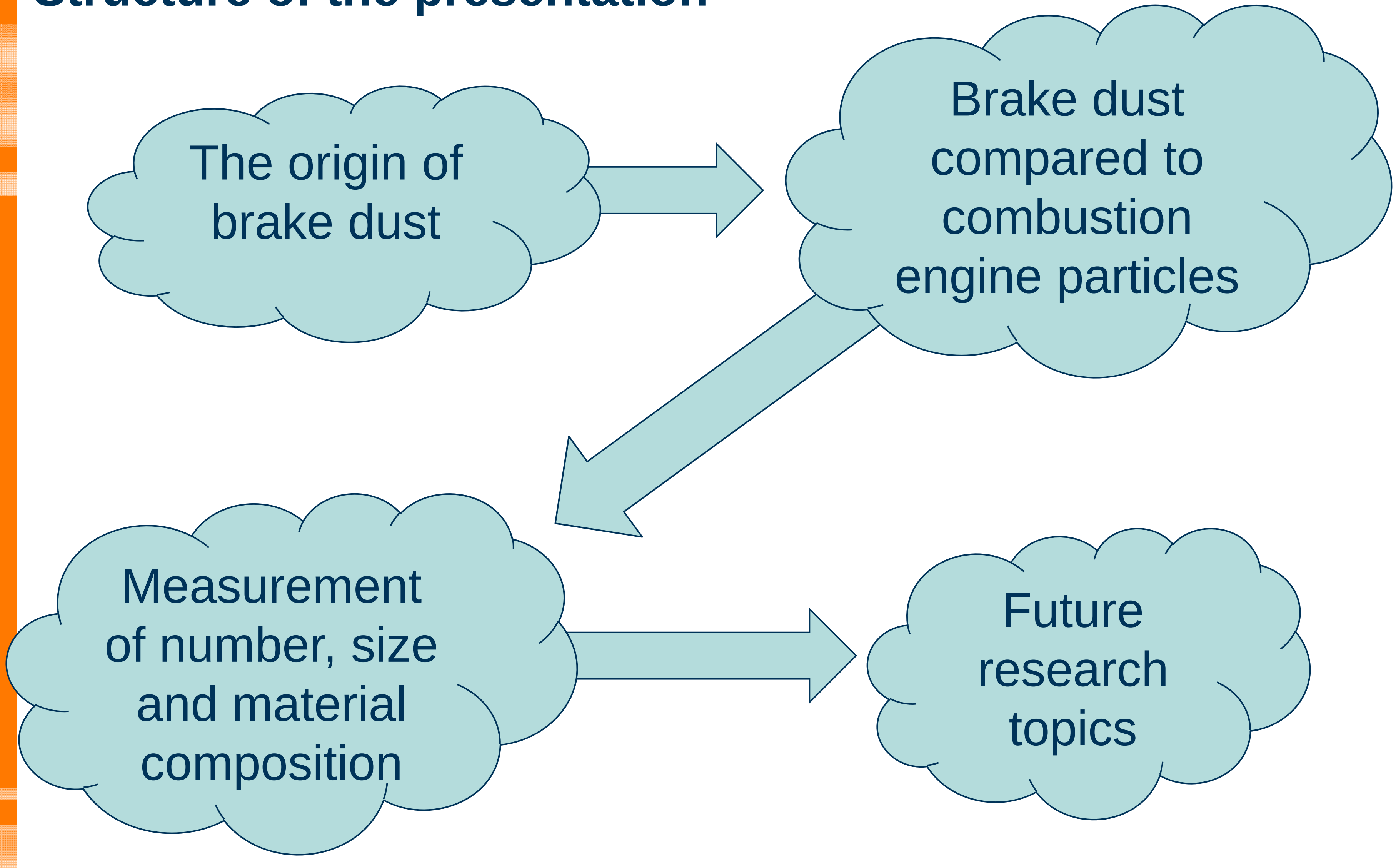
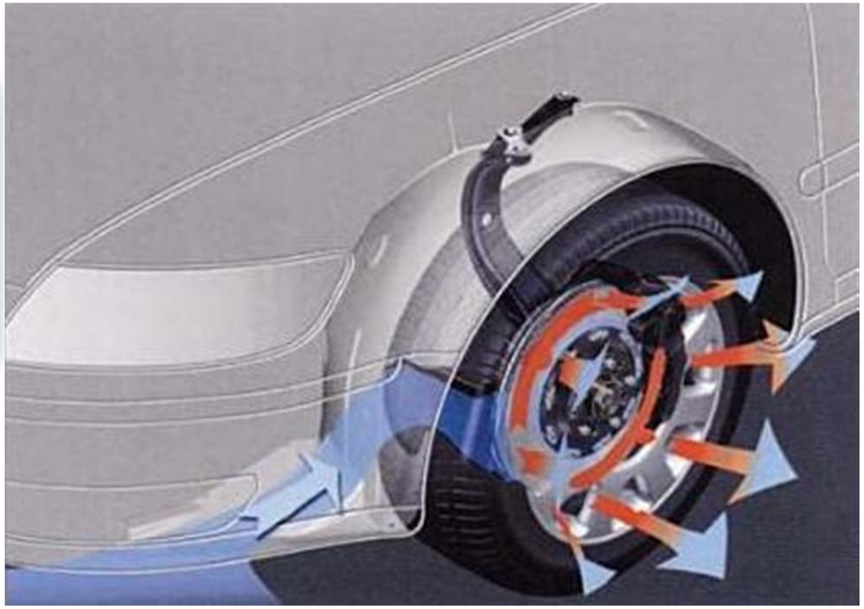
Structure of the presentation

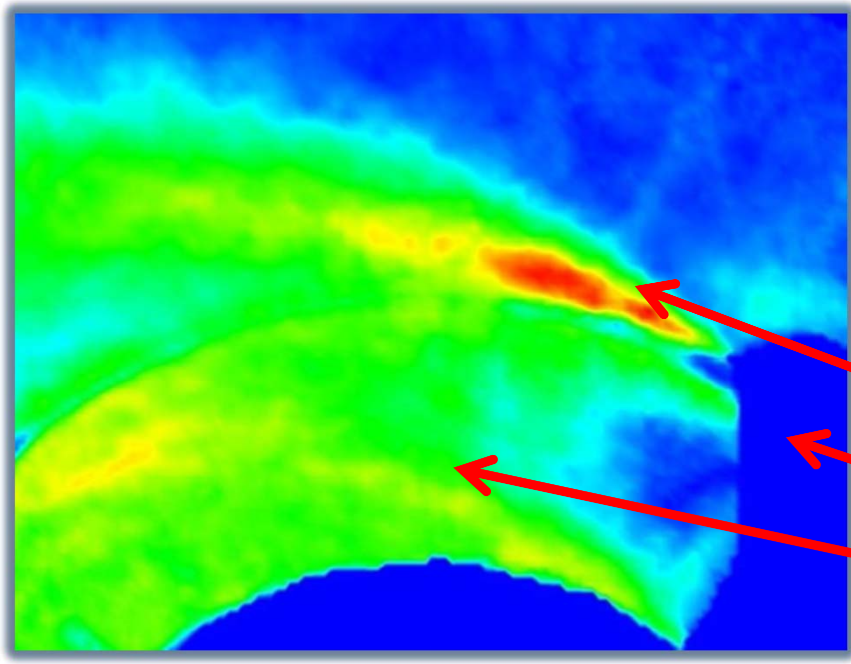


Origin of brake dust

During a braking incident, the main amount of brake dust is emittet behind the brake caliper in the rotating direction of the brake disc



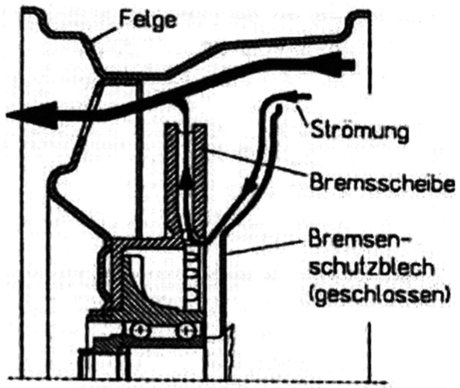
Source: VW



Particles

Brake caliper

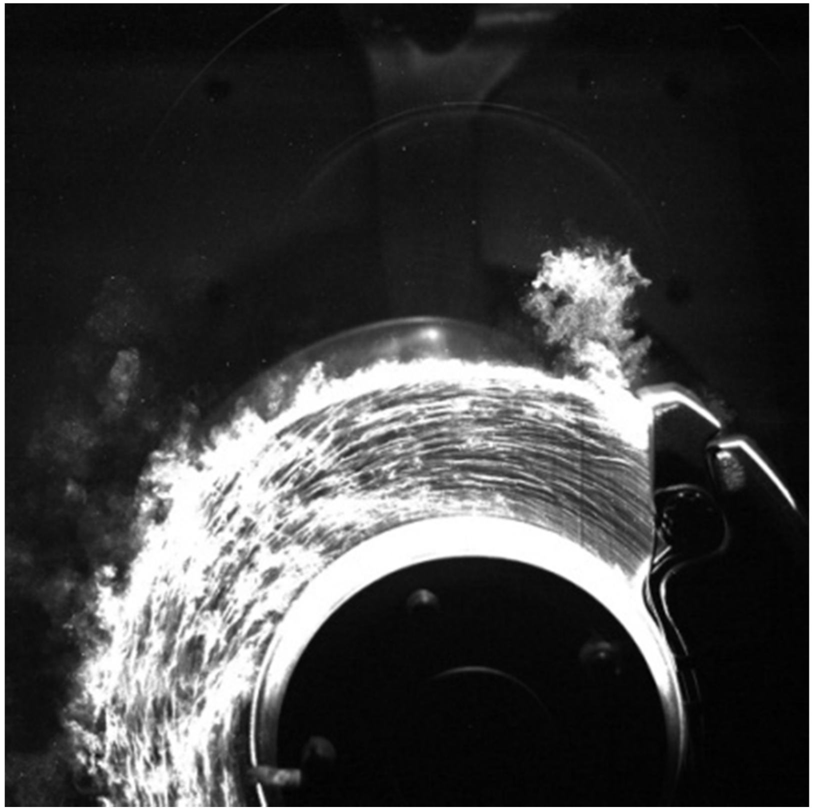
Brake disc



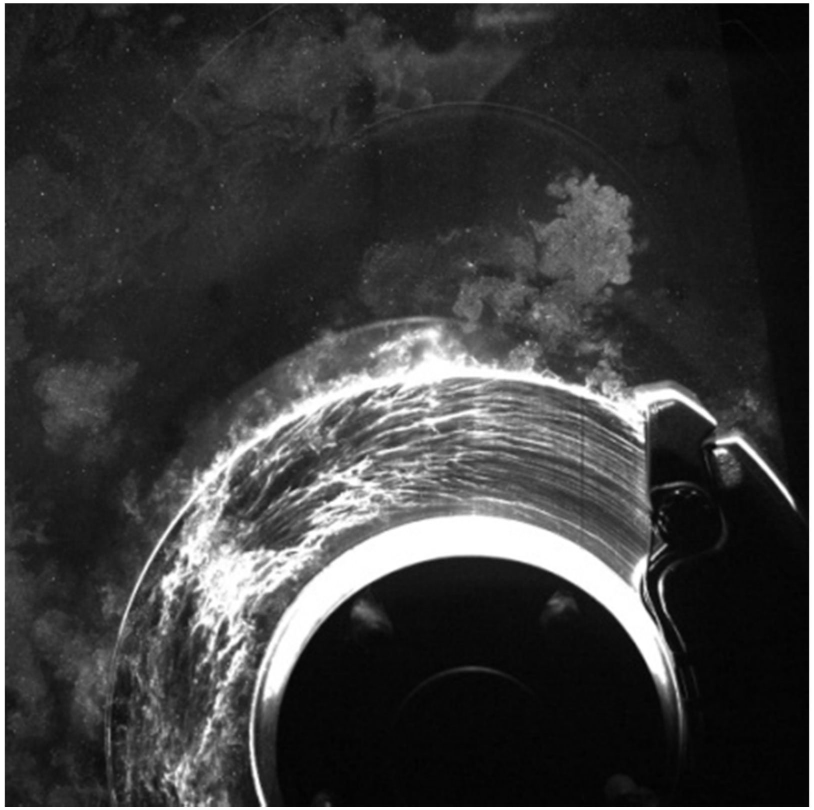
Source: Schölzel,1996

Emission behaviour
Visualisation with light section method

Beginning of braking

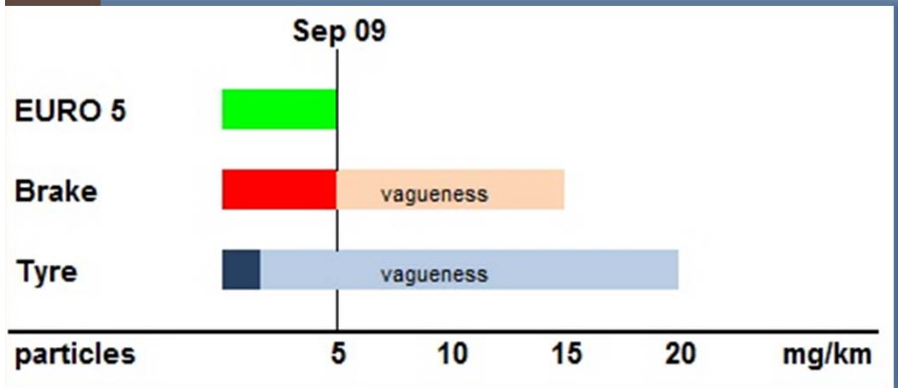


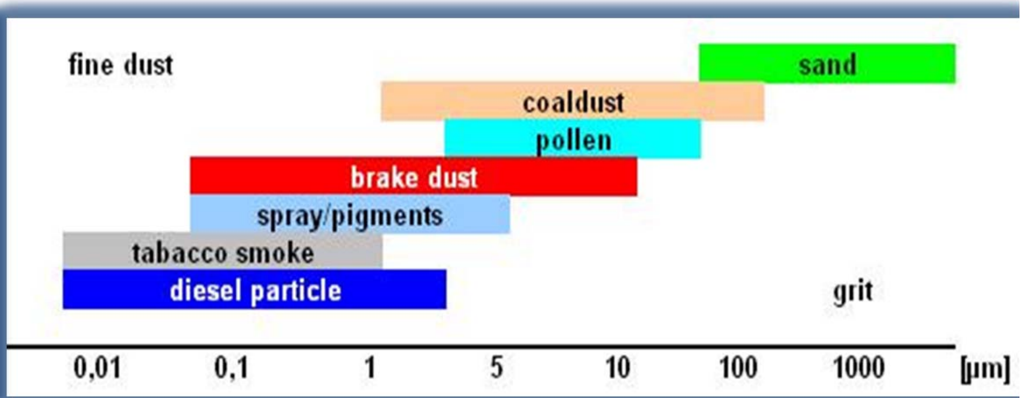
After 1000 ms



Classification of brake dust

Calculations* assume an emittet mass of particles of 5 - 15mg/km for a passengers car. This dimension compared to the regulative laws for EURO5 engines and the material composition of brake dust could lead to legislative liabilities of brake manufacturers or OEMs





*Environmental Agency Austria, US state California with EMFAC7g model, EPA with BILEG6 and PMFAC model

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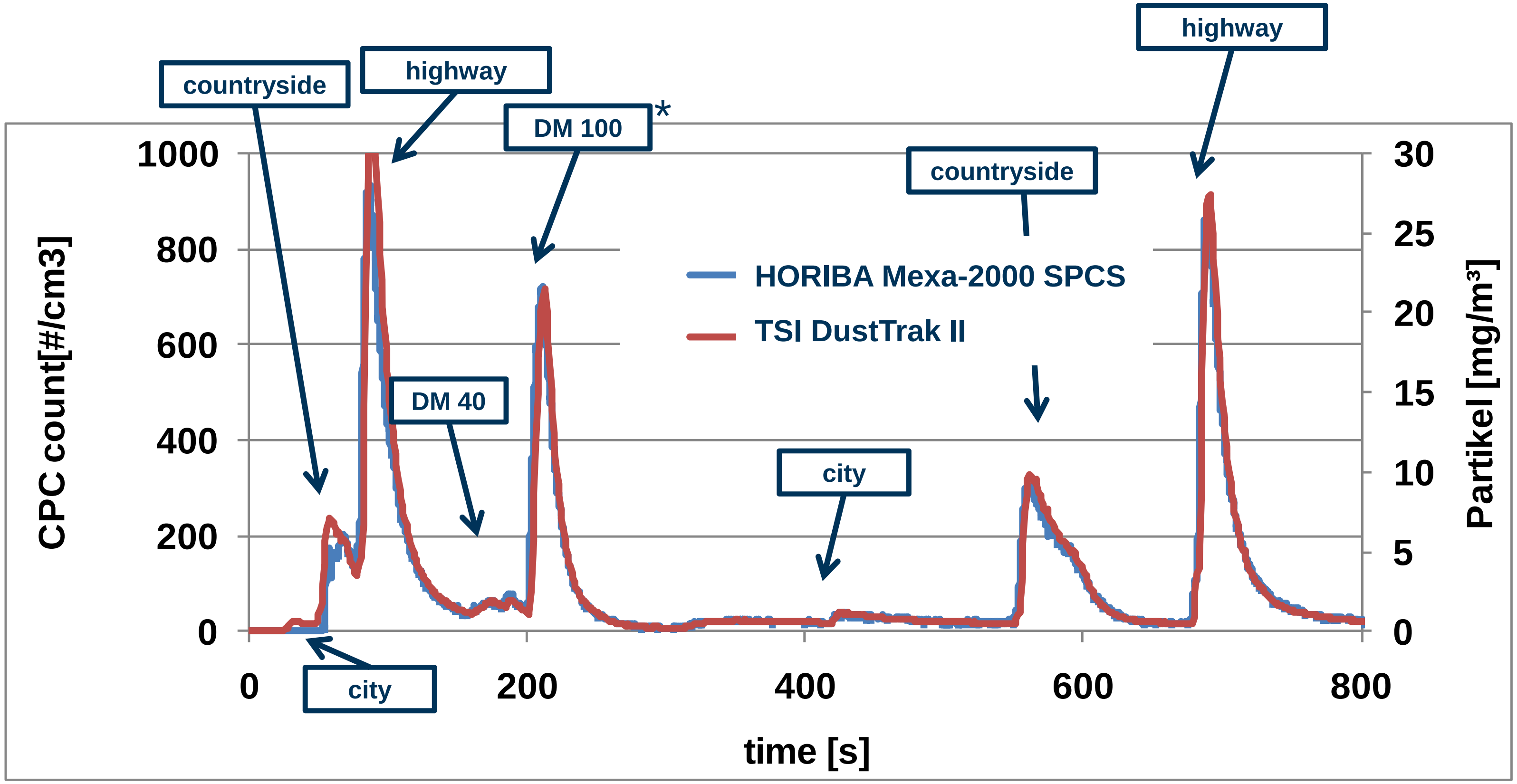
Measuring the number and mass of airborne particles

Evaluation of different braking scenarios with light-section method (laser light)→
Amount of particles off-brake highway = amount of particles city stop

City | **Countryside** | **Highway**

Exponential growth
of particle emissions

Measuring the number and mass of airborne particles



→Exponential increase of particle emission with higher braking energy

* Drag mode 100km/h

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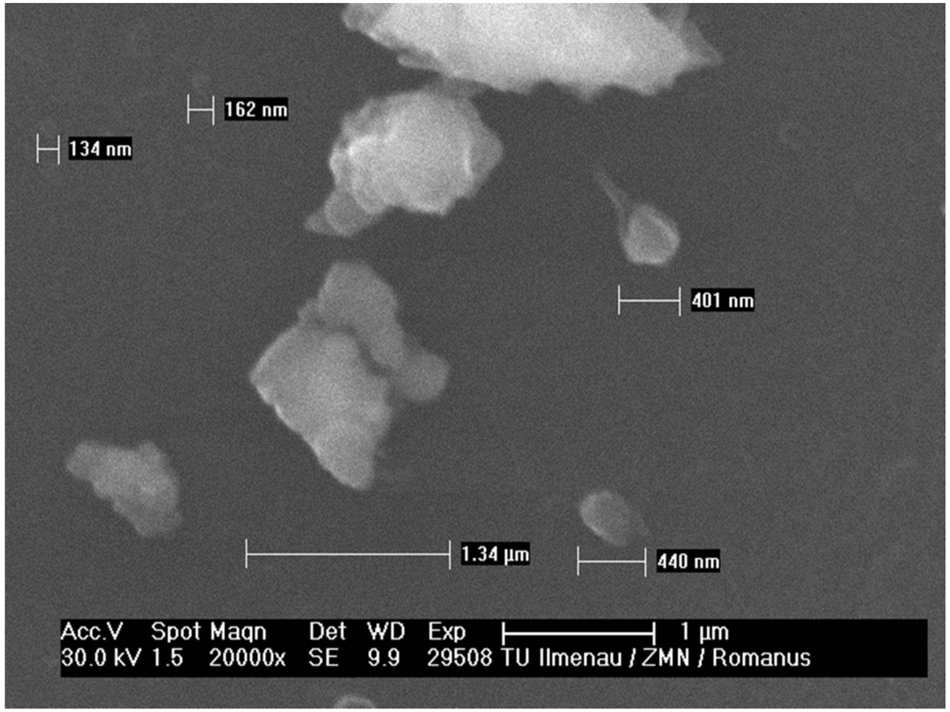
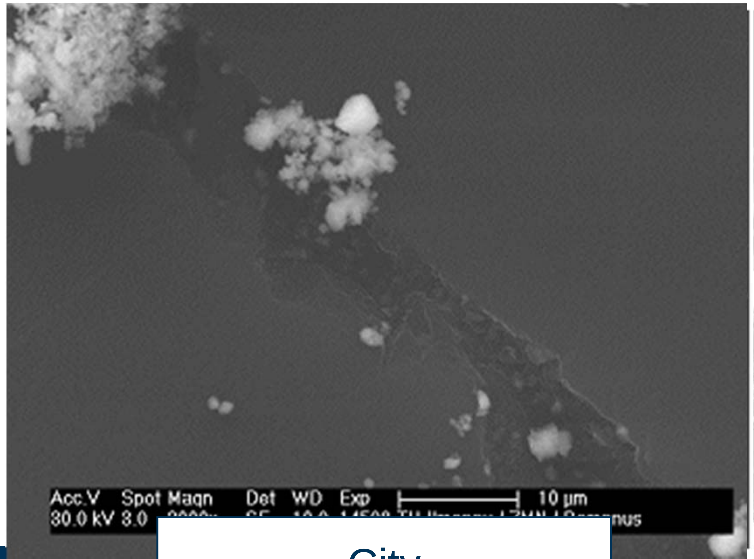
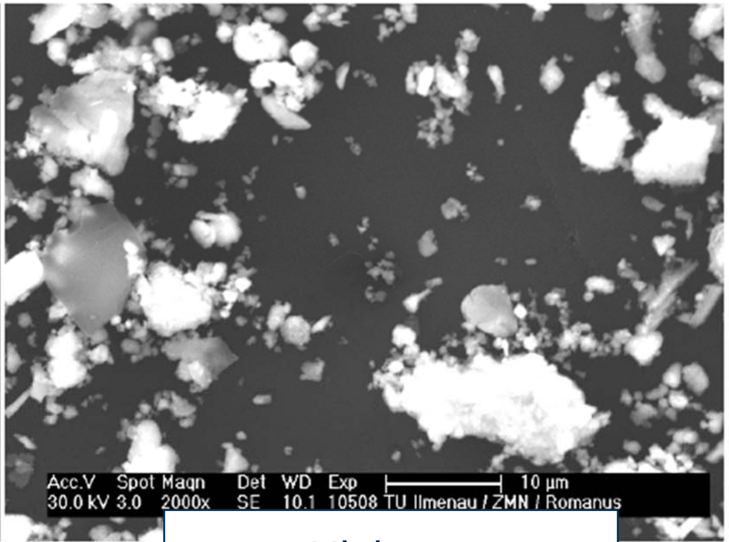
Particle size

→ **Different particle sizes dependant on the braking scenario**
→ **Main amount of particles under 500nm**





City

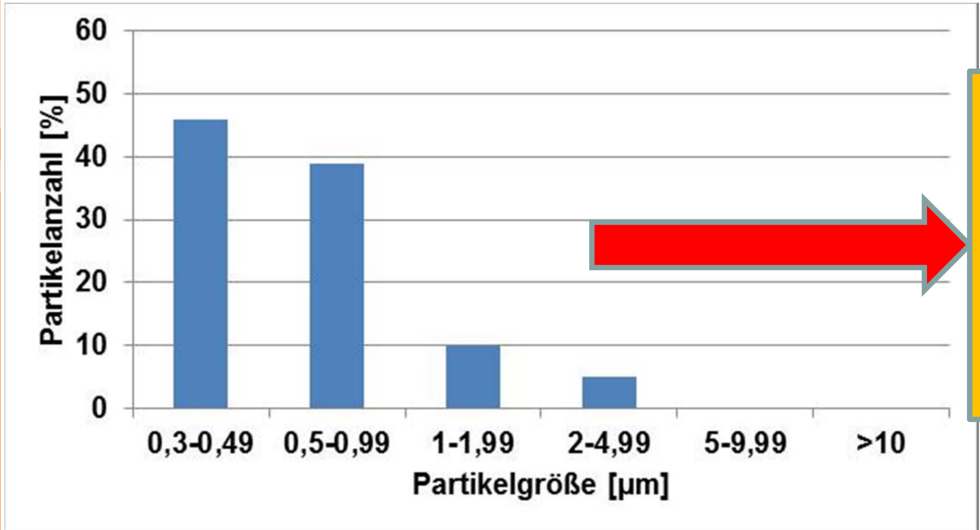


Highway

Particle size

Measurement of airborne particels

→ 6 channel particle sizer (Fluke 983)

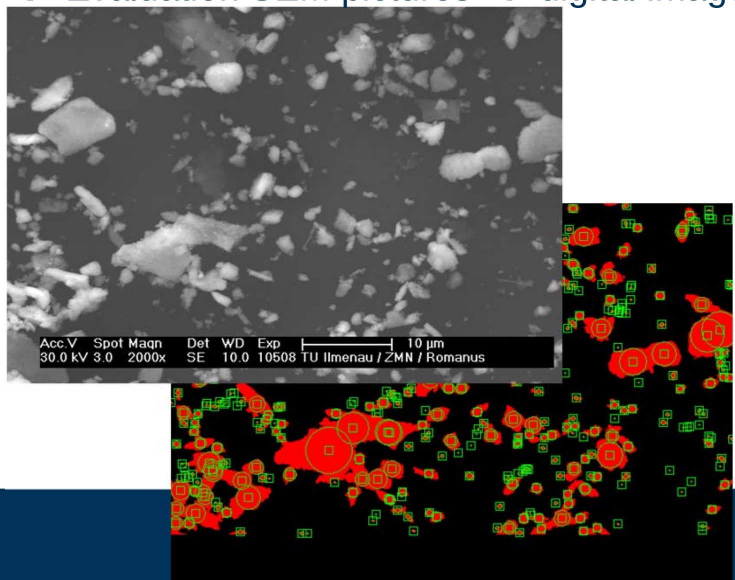


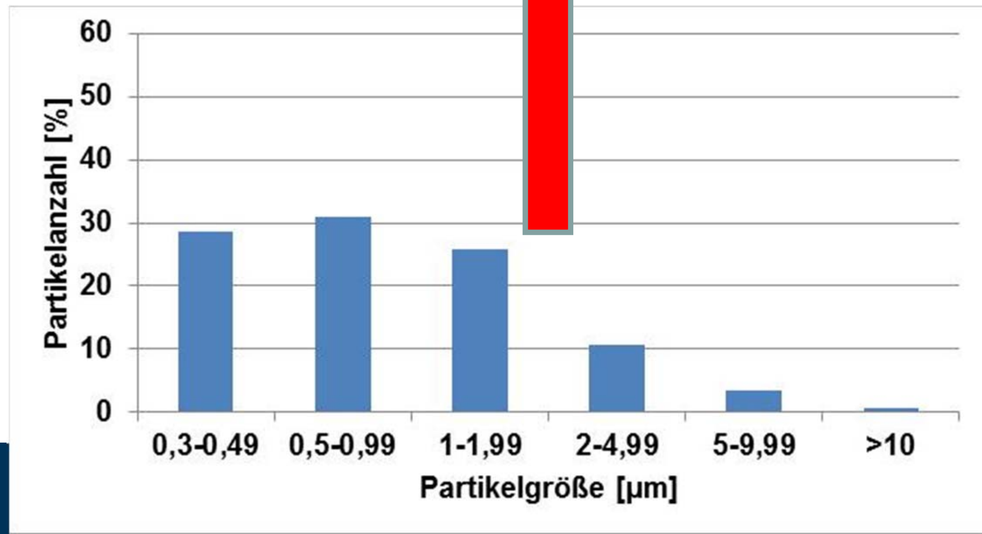
Increasing number of particles > 1 µm

→Agglomeration between emission and sedimentation

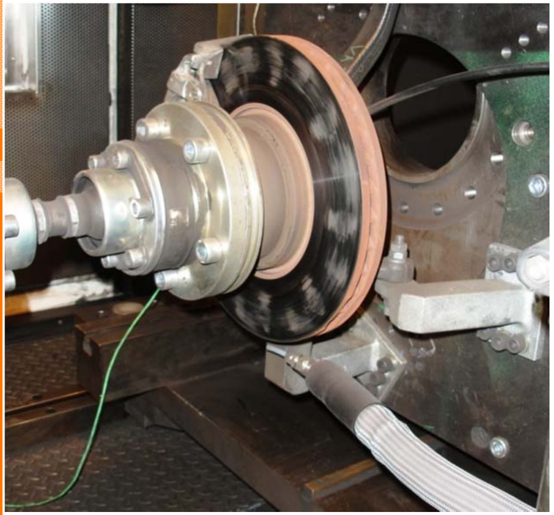
Measurement of sedimented particels

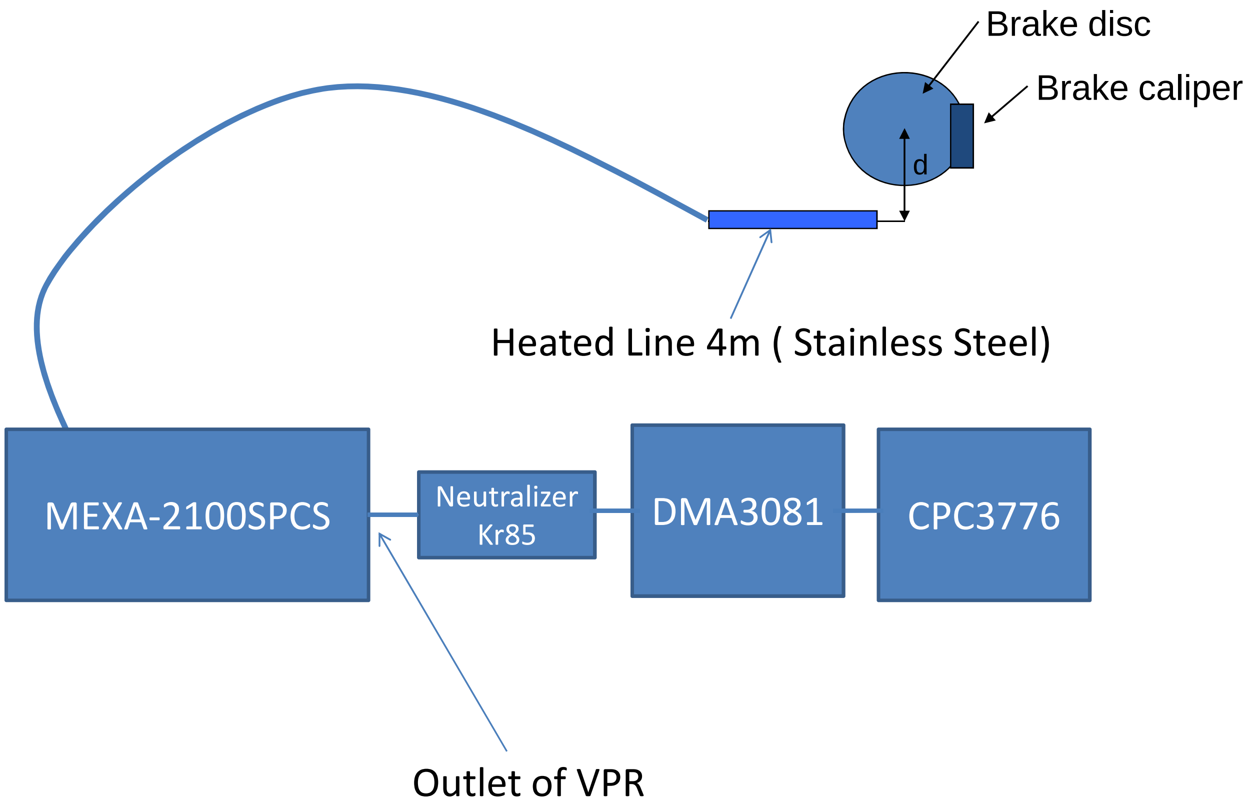
→ Evaluation SEM pictures → digital image processing





Particle size - measurement with a HORIBA Mexa-2100SPCS





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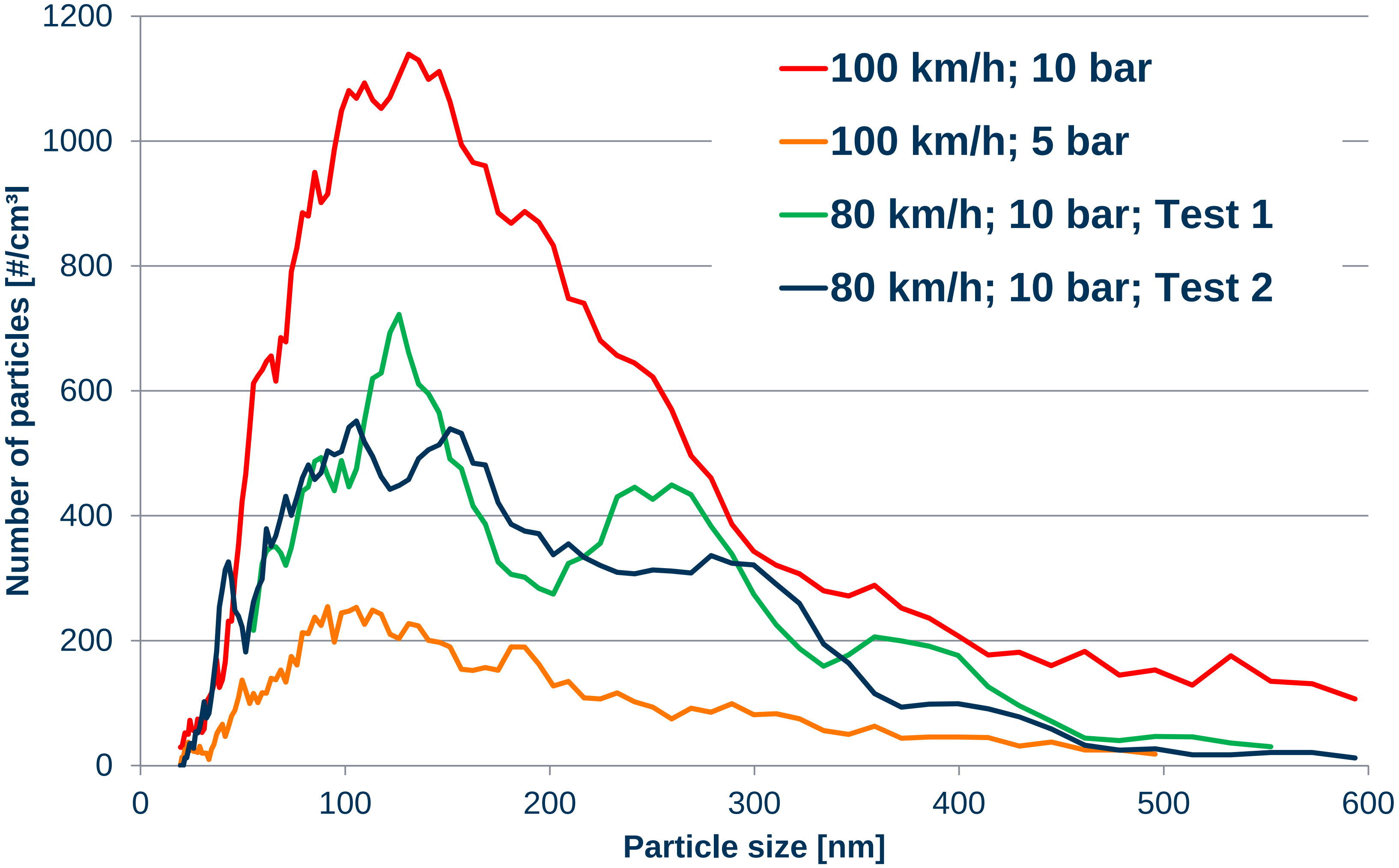
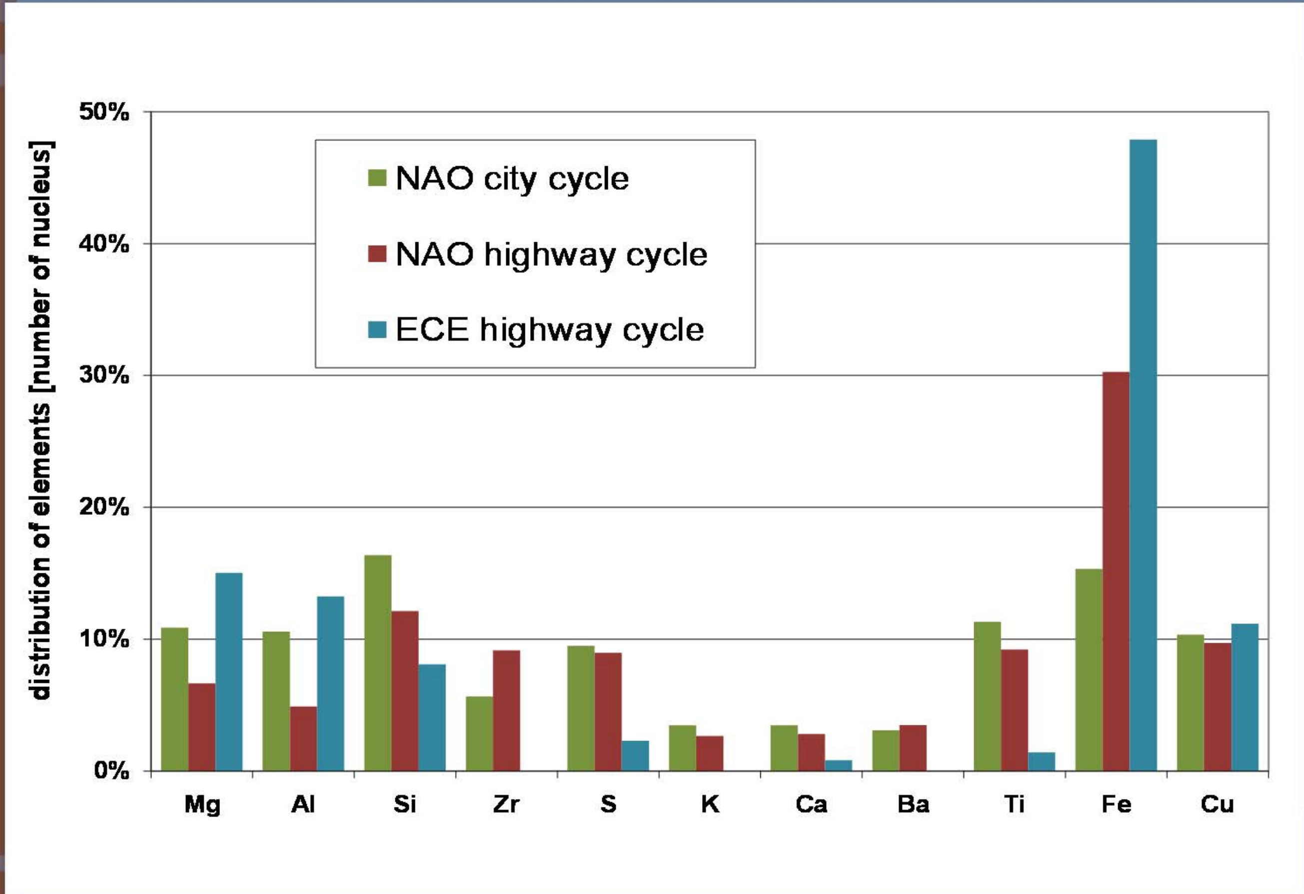
Particle size - measurement with a HORIBA mexa 2100SPCS



Composition of brake dust – SEM-EDX (energy dispersive x-ray spectroscopy)



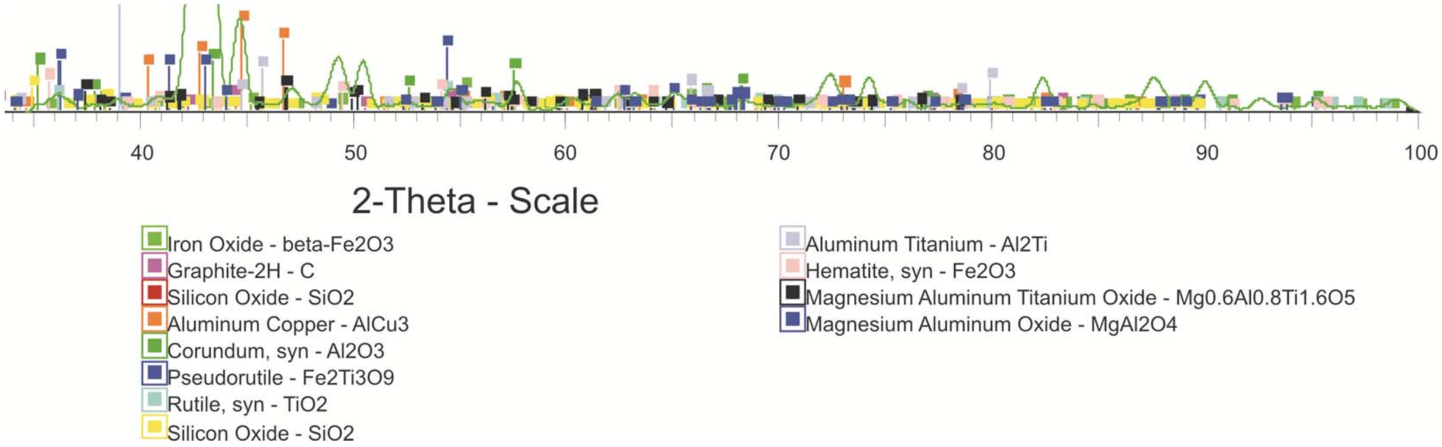
→ **Magnitude of elements in brake dust; no information about molecular composition; measured with a SEM-EDX Philipps XL30**

Future research topics

Tribological behaviour in the friction zone

→ **Experiments with a borosilicate glas instead of iron brake disc allows the monitoring of the friction zone**

Accurate composition of brake dust – XRD (x-ray diffraction)



Summary

- Regulation of brake emission by legislature is possible

- For the measurement of number and size of particles, existing methods from the exhaust emission technology are suitable

- The size and number of brake dust particles depends on the braking scenario as well as the material of the brake pads

- Future research topics focus on the tribological behaviour in the friction zone, as well as the material composition of the particles

Thank you for your attention