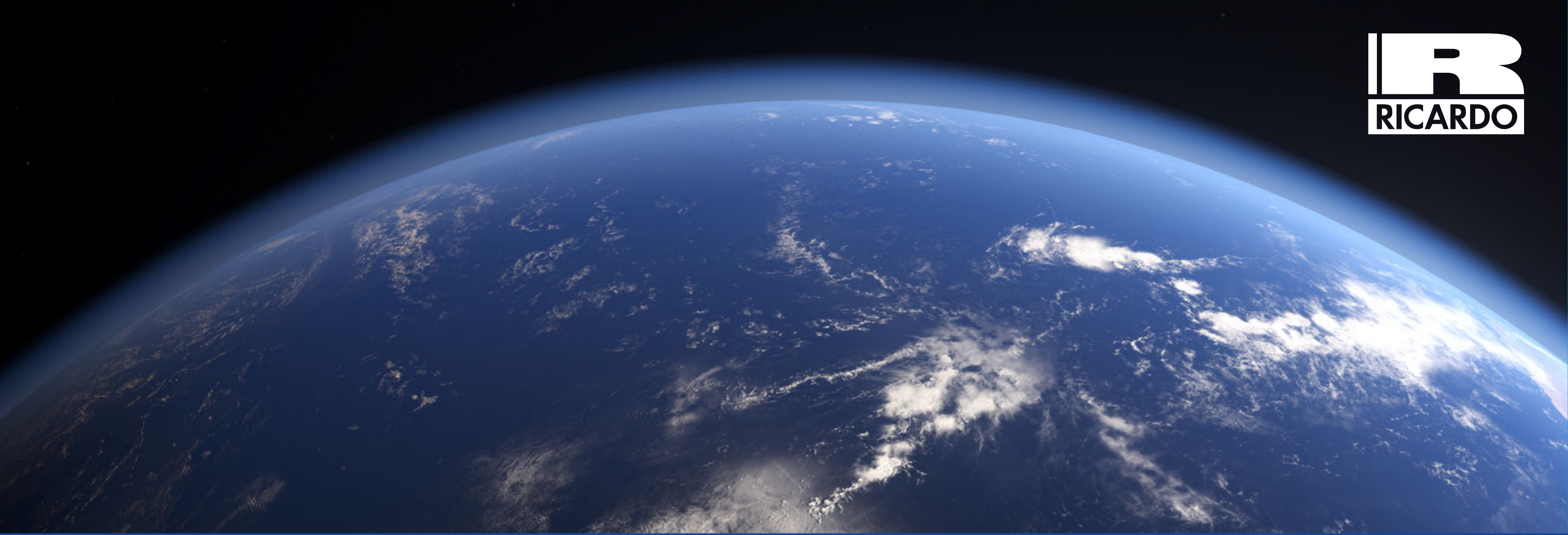

DfT Brake and Tyre Programme Phase 2: Emissions of PN10 and PM2.5 from brake systems during chassis dynamometer testing

18th June 2025, 28th ETH Nanoparticles Conference (NPC-25)

Jon Andersson, Louisa Kramer, Jason Southgate, Ian Marshall, Gary Waite, Simon de Vries

Disclaimer

- At the date presented, 18th June 2025, the information contained in this presentation represents preliminary results from an ongoing project
- While the work is complete, the report is still subject to review and approval
- Therefore, the results and conclusions shared here are not final and may be subject to change. Please consider this when interpreting the data and findings

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Introduction

- **Policy Problem**
- Non-exhaust emissions (NEE) from brake wear, tyre wear, road wear, and resuspension of dust have become a significant source of particulate matter (PM_{10} and $PM_{2.5}$)
  - But there are still large gaps in our understanding of the factors affecting NEE.
- Main focus for NEE has been on PM, but PN10 is also important to consider and is included in Euro 7
- **Client and Motivation**
- The Department for Transport (DfT) has directed research to fill these gaps and potentially inform UK Govt policy on reducing brake and tyre wear
- **Research Questions**
- In Phase 1 of the DfT project Ricardo successfully developed an approach for measuring and characterising particles emitted from brake and tyre wear, under real driving conditions. For Phase 2, the systems were optimised, and the following research questions were addressed:
  1. What variables affect particle emissions from brake and tyre wear?
  2. How do different brake and tyre components influence emissions?
  3. What is the impact of regenerative braking and particle reduction devices on NEE?
- **Importance of the Work**
- Non-exhaust emissions now dominate particulate matter emissions from road transport. Understanding and mitigating these emissions is crucial for improving air quality and public health. This study aims to provide insights that could lead to effective policy measures to reduce NEE.

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Phase 1 Summary

Aim: To develop an on-board approach to measure brake and tyre wear particles

Approach:

In developing the system there was a need to consider:

- A common sampling system and measurement equipment for both brake and tyre wear
- Representative sample collection of particles from brake or tyre wear
- Repeatable and reproducible measurements
- Careful consideration of background particles
- Power and spatial demands of the system

Outcomes:

The system was installed on the front driver wheel of a small light duty van and consisted of:

1) a brake enclosure to sample particles from brake wear
2) a tyre duct fixed to the wheel hub carrier to sample particles from behind the tyre
3) sampling probes for ambient measurements of particles

Testing was successfully undertaken in a chassis dynamometer facility; on a nearby test-track; and on-road in an urban environment

Brakes - Real-time particle number and mass emissions corresponded to real-time braking events, lowest emissions were seen at lowest speeds

Tyres - Non-volatile PN, and PM, emissions can be related to individual braking events on the chassis dynamometer, but not easily on the track or road

Repeated aggressive braking events lead to outgassing of volatile materials from tyres

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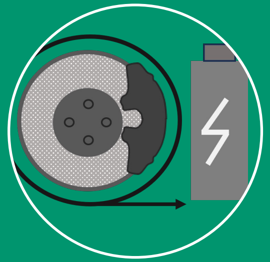
Phase 2 Objectives

Investigate the influence of different variables affecting particle emissions from brake and tyre wear, and determine typical emissions levels to assist in developing emissions factors

Variations in brake and disc materials

Age (mileage) of the brake components

Driving speeds and dynamics



Use of regenerative braking for hybrid and EV vehicles

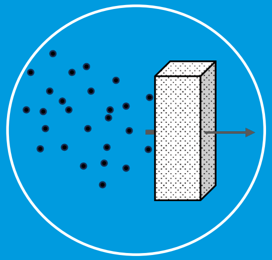
Effects of vehicle mass

Variations in tyre composition

Age of the tyre

Tyre sizes

Driving speeds and dynamics



Technologies aimed at reducing particle emissions

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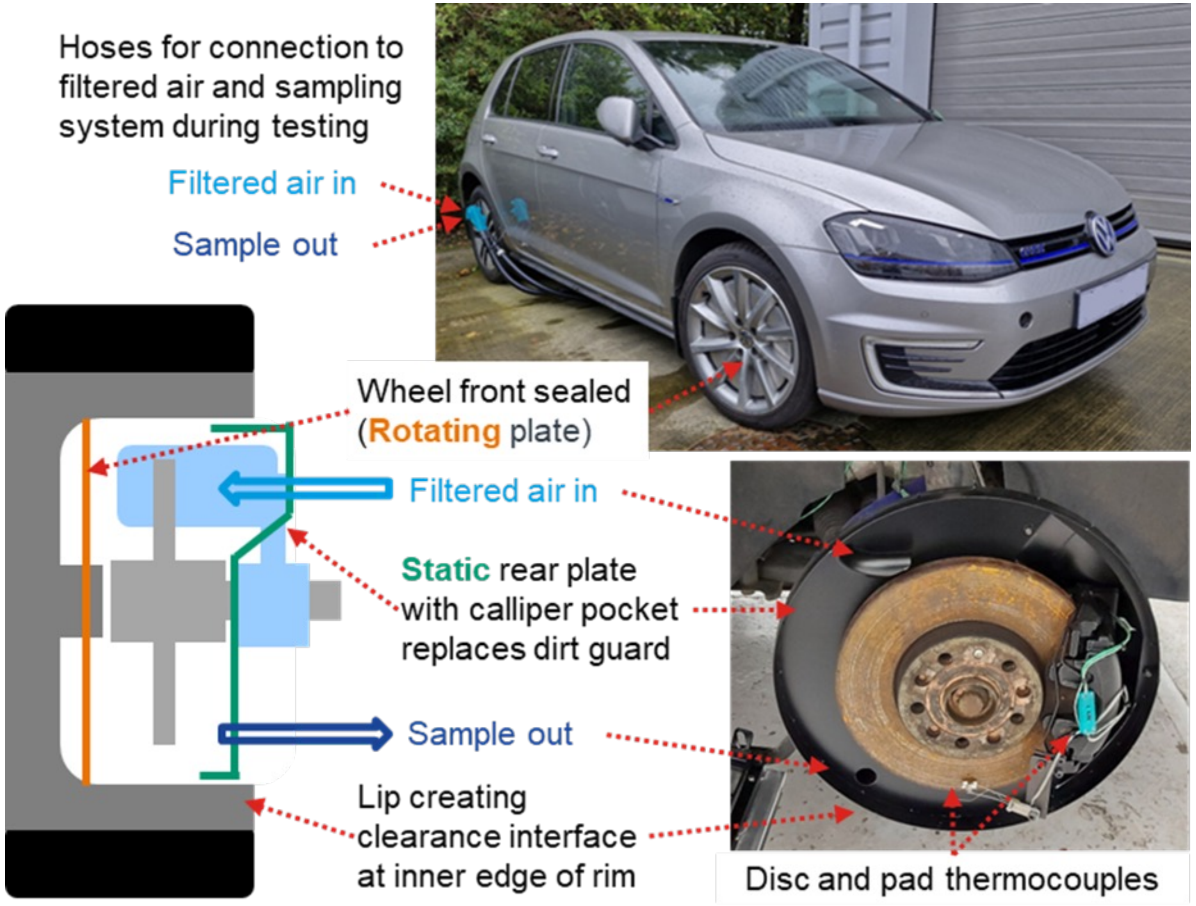
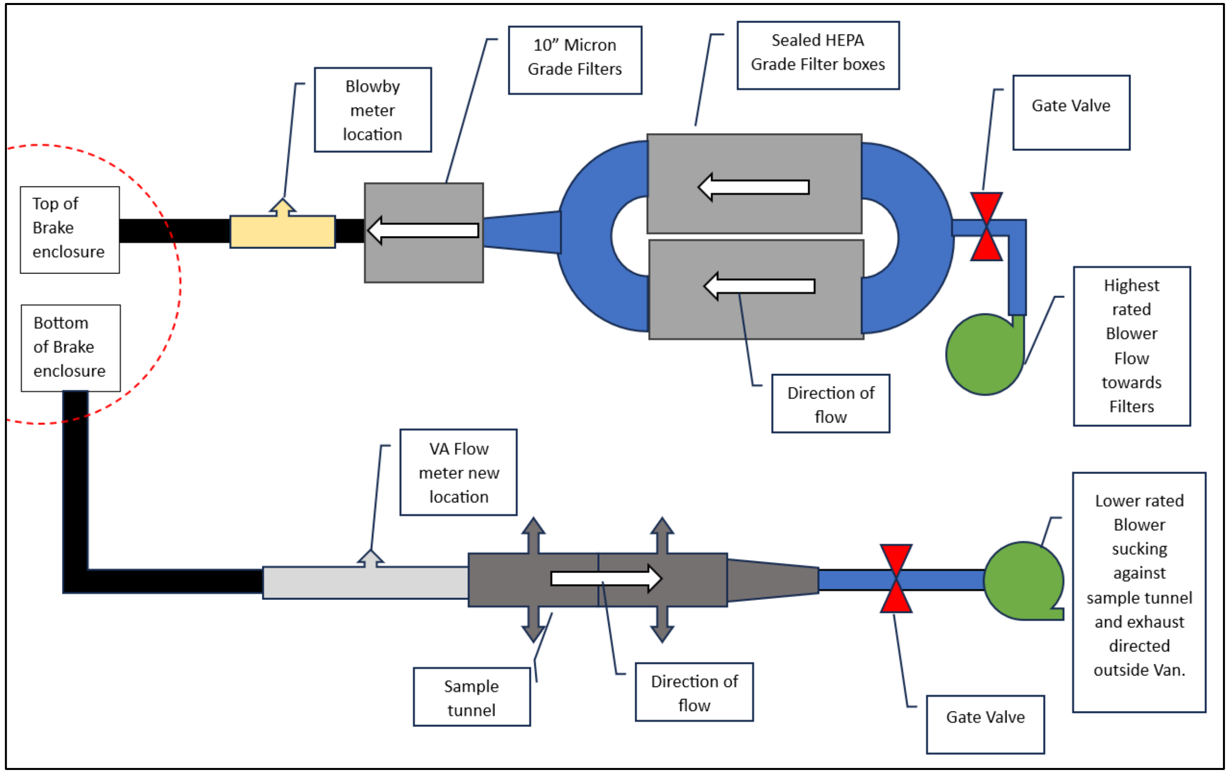
Test Vehicle – VW Caddy

- Several vehicles were used for testing brake emissions in this project, these included **VW Caddy (ICE),** VW Golf GTE (PHEV) and VW e-GOLF (EV)
- Measurements were made from the right-hand side front wheel only, using a specially designed enclosure
- For the results shown, tests were conducted on the VW Caddy on a **2WD chassis dynamometer, meaning that braking forces were applied to the front wheels only**
- PM2.5 and PN10 results are presented per front wheel

Sampling System - Brakes





For the VW Caddy the measurement equipment could be installed on-board or tested off-board, for other vehicles the testing on chassis dyno was executed with the equipment on a trolley

Measurement equipment used during Phase 2 brake emissions testing

Metric	Instrument
PM2.5 in the lab/on road (real-time and gravimetric)	**Dekati eFilter (PM2.5)**
Non-volatile PN10 in the lab	**AVL APC+ (PN10)**
Non/low-volatility PN10 in the lab/on road	Dekati Hot MPEC+ (PN10)
Total PN10 in the lab/on road	Dekati Cold MPEC+ (PN10)
Particle size distribution 5nm to 2500nm in the lab	Cambustion DMS500

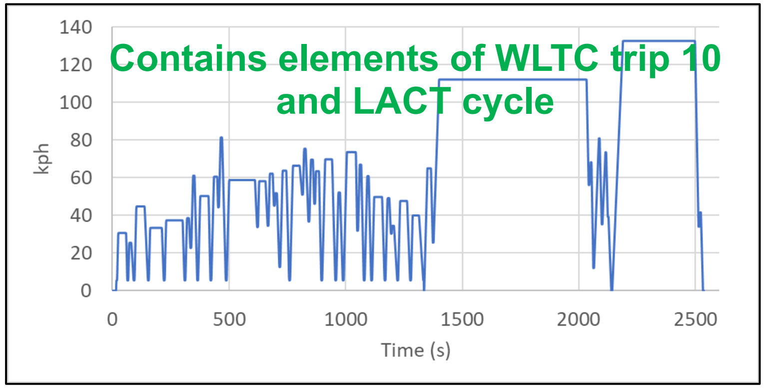
Data shown

Additional measurements were also taken, including vehicle speed, brake fluid pressure, brake temperature, tyre temperature and air flow

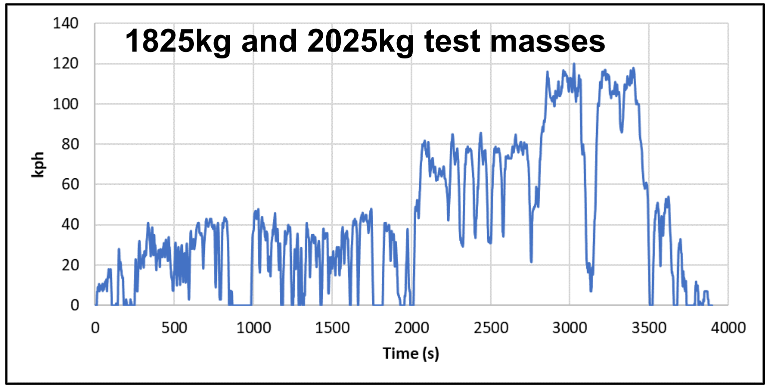
Test Cycles

Seven different drive cycles were used in the testing; here emissions results focus on the PG42 cycle

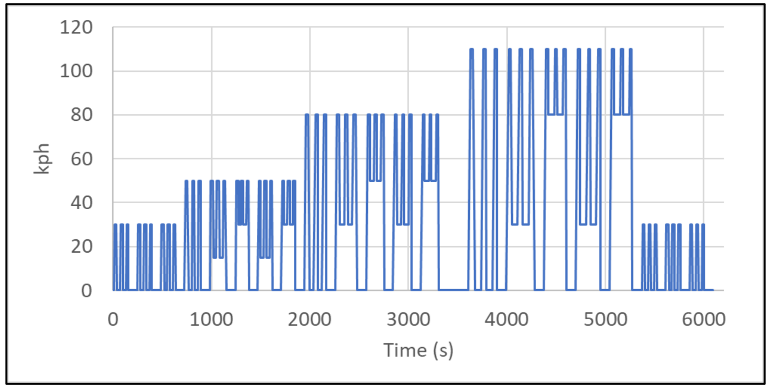
PG42 - high particle emitting cycle



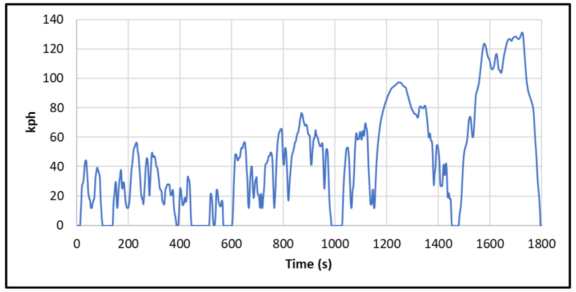
On dyno RDE - real driving emissions



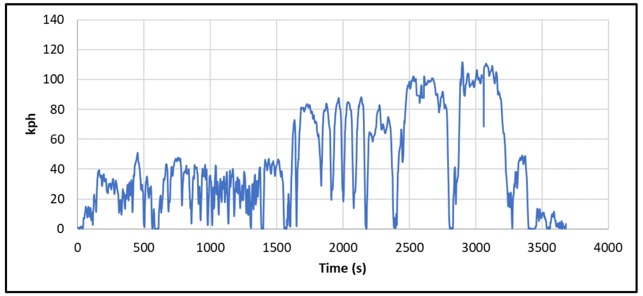
Bespoke – specified braking events



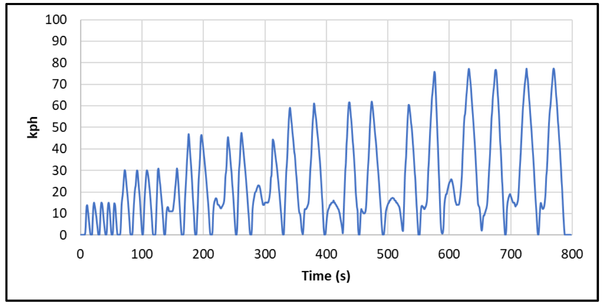
WLTC - certification cycle



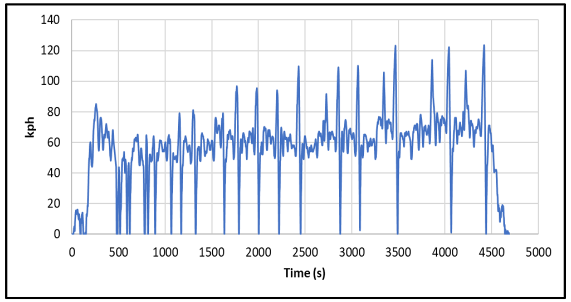
Road RDE - real driving emissions



Drive-by track - braking events up to 50 mph

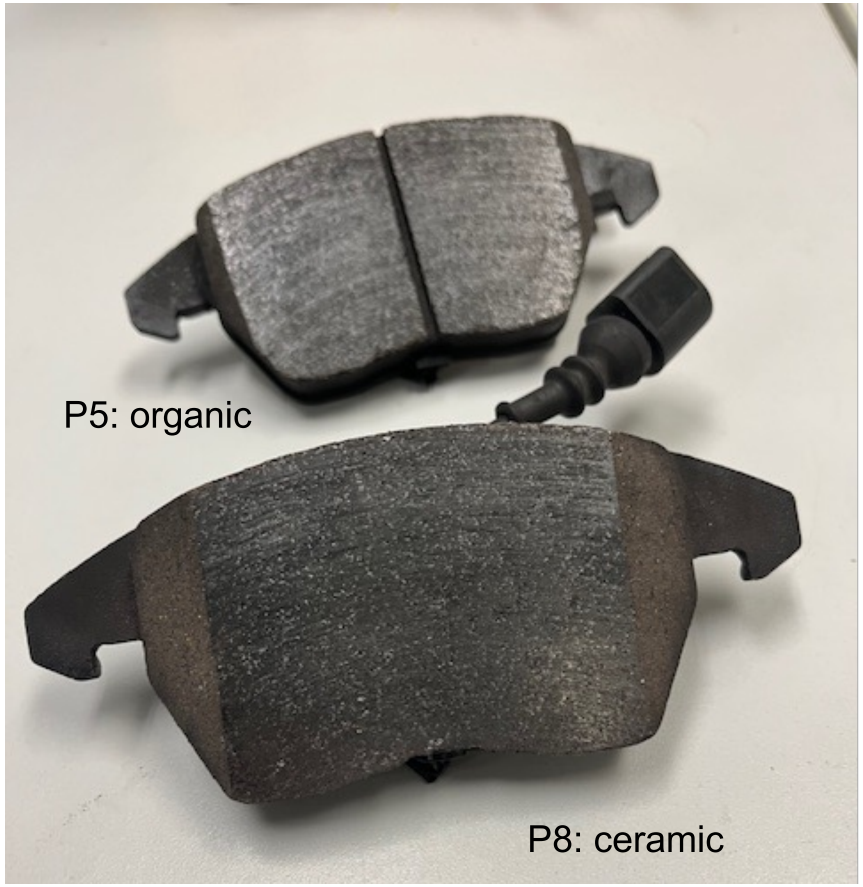


High speed track - braking events up to 80 mph



Components Tested - Brakes

Disc ref	Disc	Pad ref	Pad cost	Pad description / material
D1	"Low cost"	P1	£££	Premium brake pad
		P2	£	“Budget” brake pad
		P3	£	“Budget” brake pad
		P4	££	"Low-metallic" brake pad
		P5	££	Organic friction material
		P6	£	“Budget” brake pad
		P7	£££	Premium brake pad
		P8	£££	Low dust brake pad - Ceramic
		P9	£££	Low dust brake pads
		P10A	£££	As P1 but aged pad ~ 50,000 km
D2	"Premium" brand	P1	£££	P1 tested with premium disc



Px = service pads, Dx = service disc

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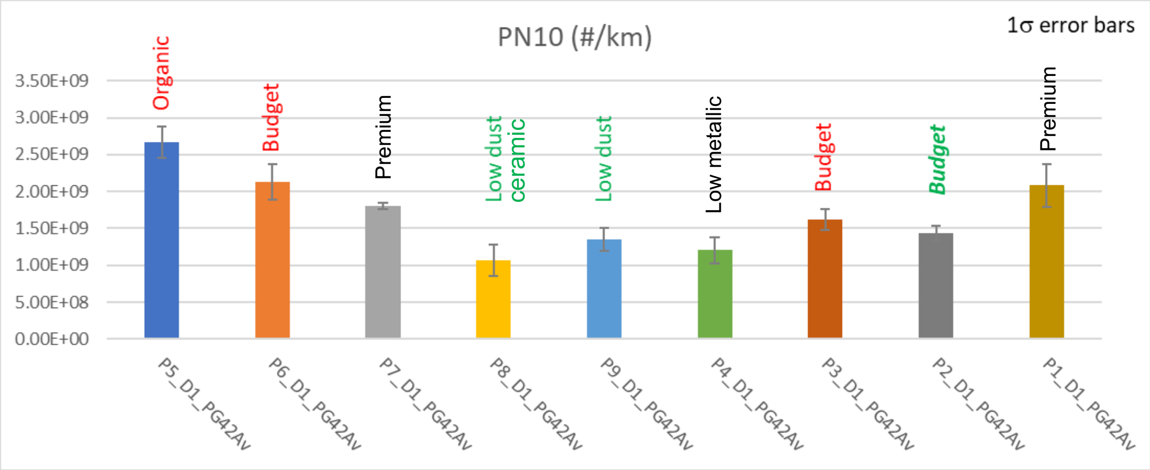
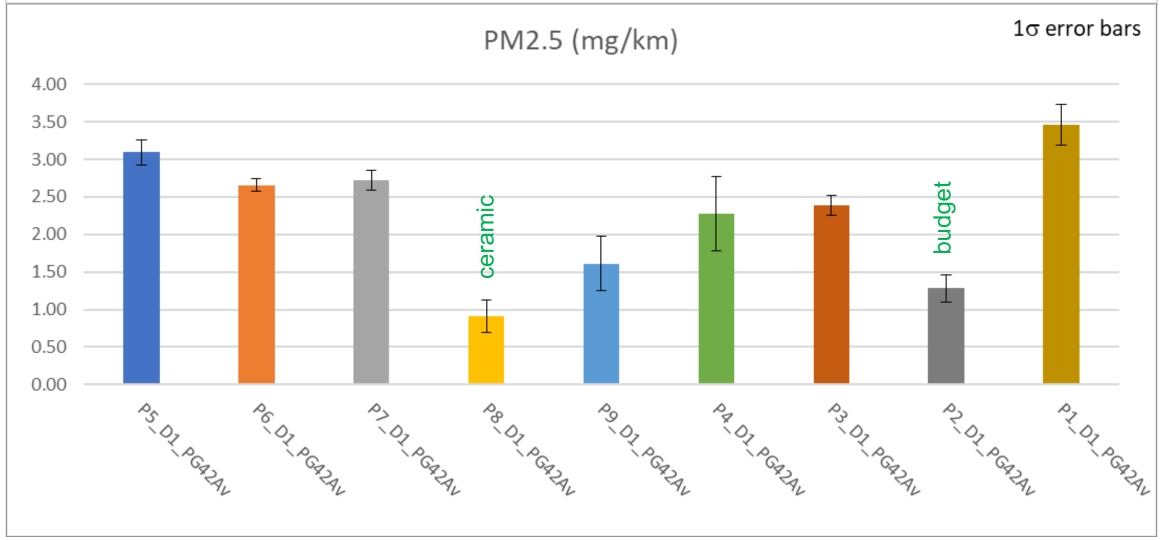
PN10 and $PM_{2.5}$ emissions from different pad types when tested with the same disc, PG42 cycle





Scope

- 9 different pad types all tested with the budget disc (D1)

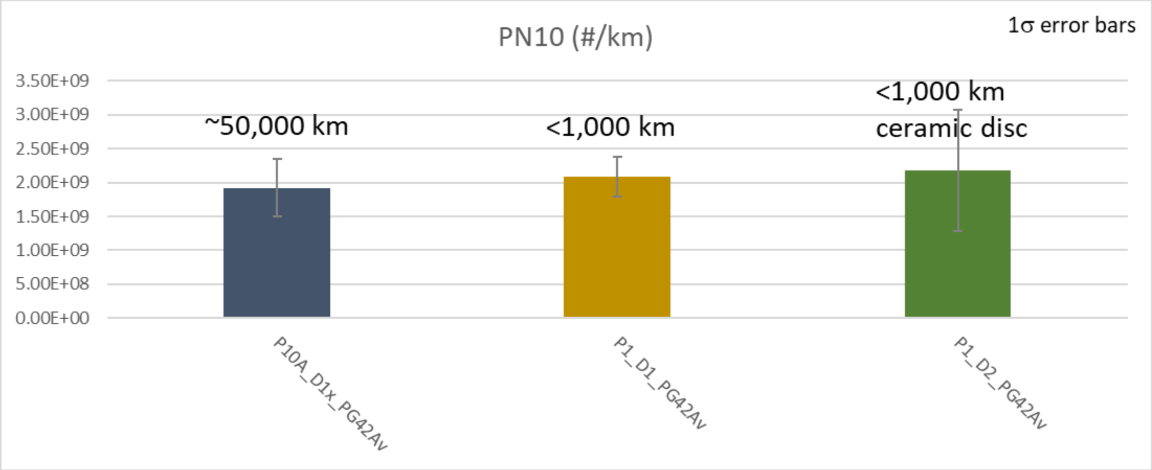
Outcomes

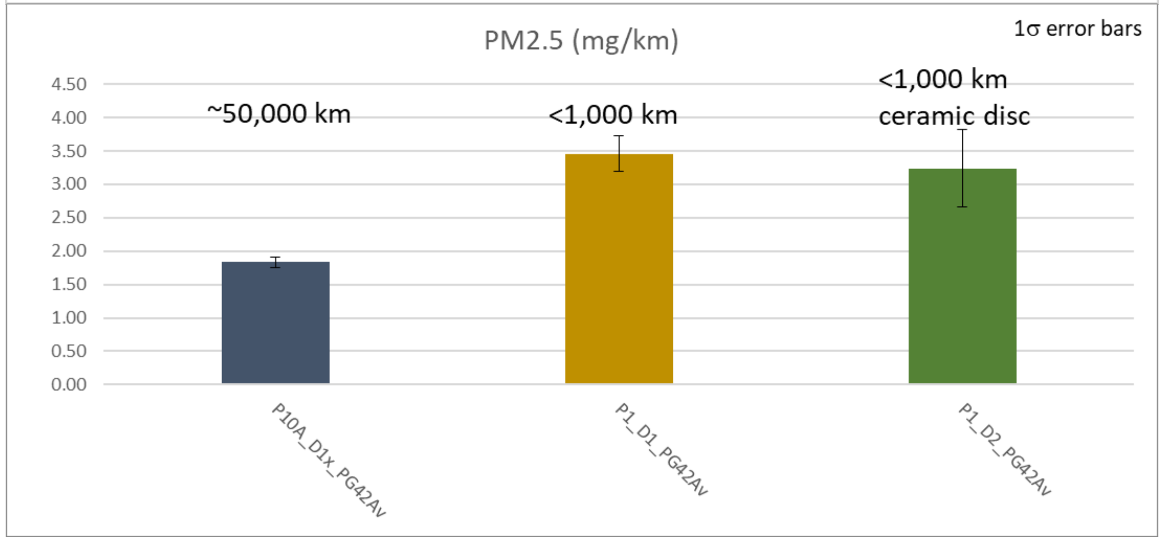
- Good repeatability, enabling discrimination between pads (1σ error bars)
- Larger differentiation between pads in $PM_{2.5}$ than PN10 emissions
- Lowest emissions from P8 (ceramic) and P9 (low dust) in both PN10 and $PM_{2.5}$ emissions
- Generally highest PN10 and $PM_{2.5}$ emissions from 'organic' pads (P5) and budget pads (P3, P6)
- Alternatively, budget pad P2 was amongst the lowest $PM_{2.5}$ emitters

Headlines

- Lower PN10 emitters tend to be low $PM_{2.5}$ emitters
- Low dust and ceramic labelled pads have lowest emissions
- Budget label does not *necessarily* indicate high emissions

Impact of high mileage pads and ceramic disc on PN10 and $PM_{2.5}$ emissions, PG42 cycle





Scope

- Nominally identical pad types, with ~50,000 km (P10A) and <1000 km (P1) elapsed mileages, all tested with the same budget disc (D1)
- P1 tested with a premium ceramic disc (D2)

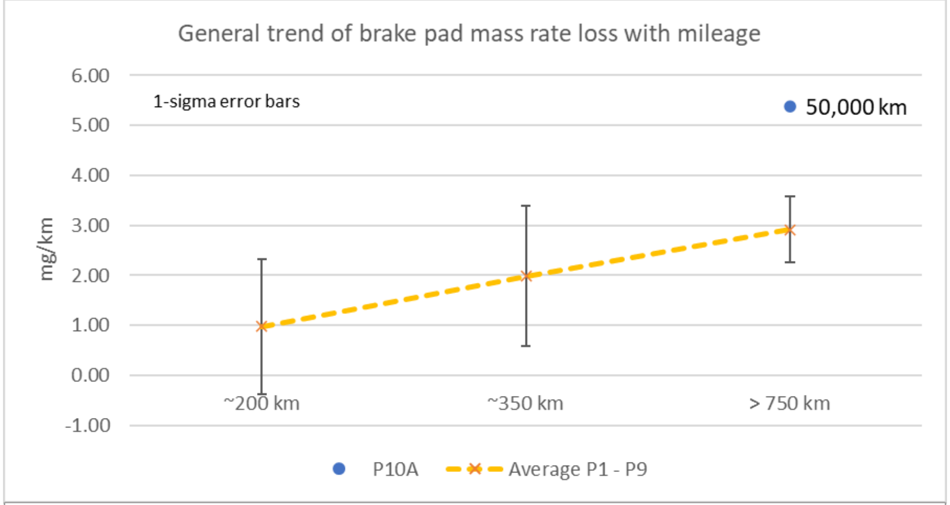
Outcomes

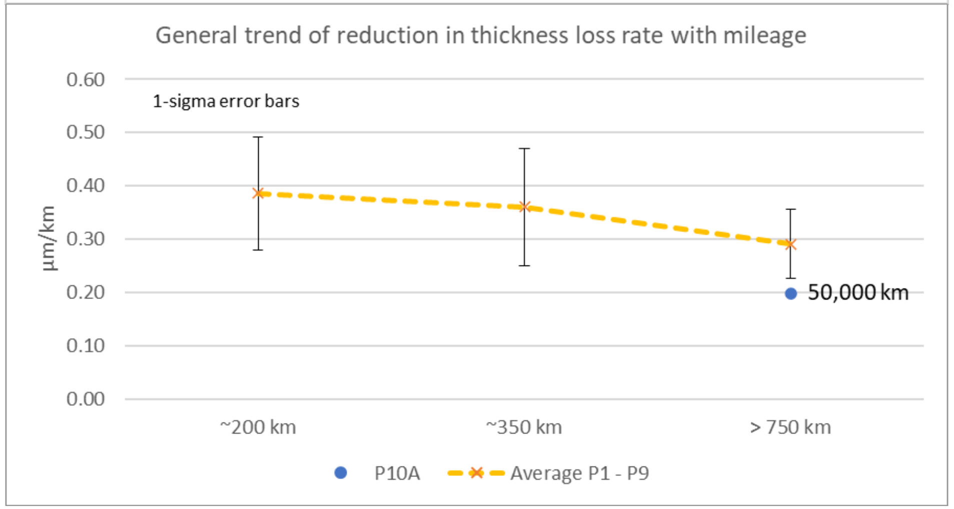
- No impact of high mileage pad, or changing to a ceramic disc, on PN10 emissions
  - Emissions consistent at around 2 x 10^9 #/km
- $PM_{2.5}$ emissions with higher mileage pads reduced by ~50% compared to lower mileage pad
- No significant impact of changing to a ceramic disc on $PM_{2.5}$ emissions

Headlines

- Minimal impact of long-term pad ageing or disc type on PN10 emissions
- Lower $PM_{2.5}$ emissions observed with higher mileage pads

Effect of increased mileage on average mass and thickness loss rates of brake pads





Scope

- Mass and thickness loss rates of 9 different pad types all determined at different mileages, and the data averaged
- Average results compared with high mileage (>50,000 km) pad

Outcomes

- Initial wear rates for pads over the first ~1000 km were ~3 mg/km
- No statistically significant differences in mass and thickness loss were observed between 200 km, 350 km and >750 km, but there were indications of underlying trends
  - Increasing rate of mass loss with higher mileage
  - Reducing rate of thickness loss with higher mileage
- Directional trends supported by high mileage pad results
- Loss rates in first 1000 km similar to those from ~1000 km to 50,000 km

Headlines

- Density of pad materials could be higher in lower layers of the pad material
- Mass and thickness loss rates slow substantially as the pad ages

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Conclusions

- Brake wear PM2.5 and PN10 were successfully sampled from tests on the chassis dyno
- For comparison of brake pad types
  - Lower PN10 emitters tend to be low $PM_{2.5}$ emitters
  - Low dust and ceramic labelled pads have lowest emissions
  - Budget label does not *necessarily* indicate high emissions, and premium label does not necessarily indicate low emissions
- High mileage pads and ceramic disc use
  - Minimal impact of long-term pad ageing or disc type on PN10 emissions
  - Lower $PM_{2.5}$ emissions observed with high mileage pads
- Pad thickness and mass loss rates with distance
  - Density of pad materials could be higher in lower layers of the pad material
  - Mass and thickness loss rates slow substantially as the pad ages

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Any questions?