TMDFRICTION
A NISSHINBO GROUP COMPANY

TMD 2015 Brake Emissions (2)

Presentation to 35th UNECE PMP Meeting
Brussels 5.3.2015

TMD Friction - Jürgen Lange

TEXTAR MINTEX DON PAGID COBREQ COSID DYNOTHERM

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Summary and recommendation to the UNECE PMP Group

Presentation to 35th UNECE PMP Meeting

1) Brake load patterns are highly important for the generated wear
   - It is not enough to have the same brake applies, if the order of braking is neglected
2) Existing test patterns for emission testing differ a lot
   - Different drive cycles lead to non comparable results
   - Driving factors are vehicle speed and deceleration (representative for brake energy and power)
3) Vehicle and brake systems influence are significant driving secondary effects
   - Depending on the primary influencing factors (speed and deceleration), vehicle and brake system design determine secondary effects that differ from car to car:
     - line pressure, friction surface pressure, rubbing speed and temperature at the friction interface are a consequence of the vehicle and brake design
     - Brake line pressure is just a consequence of weight, deceleration and system design
4) Measurements can be based on weight loss or particle emission counting
   - Weight loss measurements are established for brake components due to the expected low emissions rates a significant test distance needs to be performed (at least 20-40 cumulated NEDC cycles)
   - Emission counting seems a good qualitative overall vehicle emission monitoring approach, quantitative measurements are still missing proof of reproducibility and repeatability of sampling

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Agenda: TMD Friction Presentation to 35th UNECE PMP Meeting

Presentation to 35th UNECE PMP Meeting

TMD Friction Jürgen Lange - Senior Vice President Research & Development

Brake Emissions:

0) Introduction to brake friction
1) Brake load pattern, history and load conditions
2) Considered test patterns for emission testing
3) Brake systems influence
4) Test results for real drive cycles
5) Test results for NEDC
6) Options for wear and particle measurement

NISTMD at a Glance

In 2011 **TMD Friction** was acquired by **Nisshinbo Holdings Inc**. - a Japanese conglomerate. With this acquisition the **world's largest supplier** of friction material for the automotive industry was founded.

- **MORE THAN 6,000 EMPLOYEES WORLDWIDE**
- **MORE THAN 1,000,000 PADS PRODUCED A DAY**
- **MORE THAN € 1.3 bn. TURNOVER IN 2013/14**
- **16.9% MARKET SHARE WORLDWIDE**

RAIL | TRAILER | COMMERCIAL VEHICLE | PASSENGER CARS | RACING | INDUSTRY

NISSHINBO

Nisshinbo Holdings Inc. is a Nikkei-225-listed conglomerate founded in 1907.

- **Employees: ~22,000**
- **Turnover 2014*: €4.5 bn**

Business Areas:

- Electronic
- Chemical Products
- Photovoltaic Module Equipment
- Textile
- Paper Products
- Friction & Brakes

***Fiscal year ending March 2014**

TEXTAR | MINTEX | DON | PAGID | COBREQ | COSID INDUSTRIAL FRICTION | DYNOTHERM INDUSTRIAL FRICTION | NISSHINBO Nisshinbo Brake Inc.

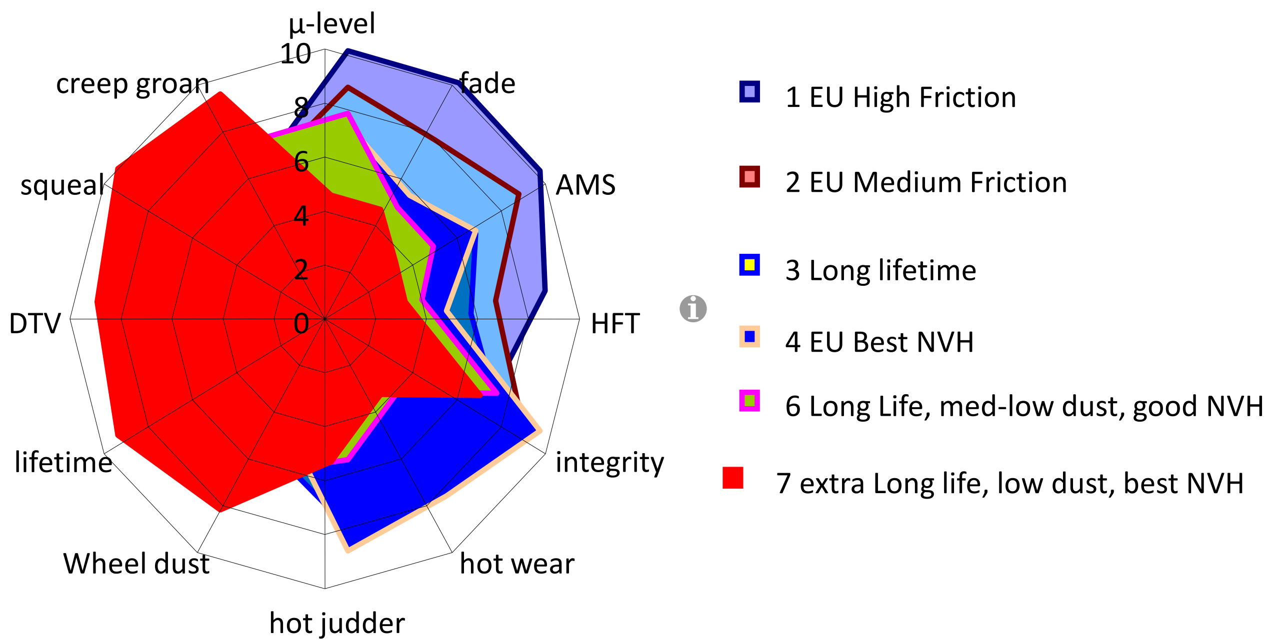
Disc Brake Products and characteristics driven by the customer requirements

Passenger Cars

Disc Brakes

PC Pads

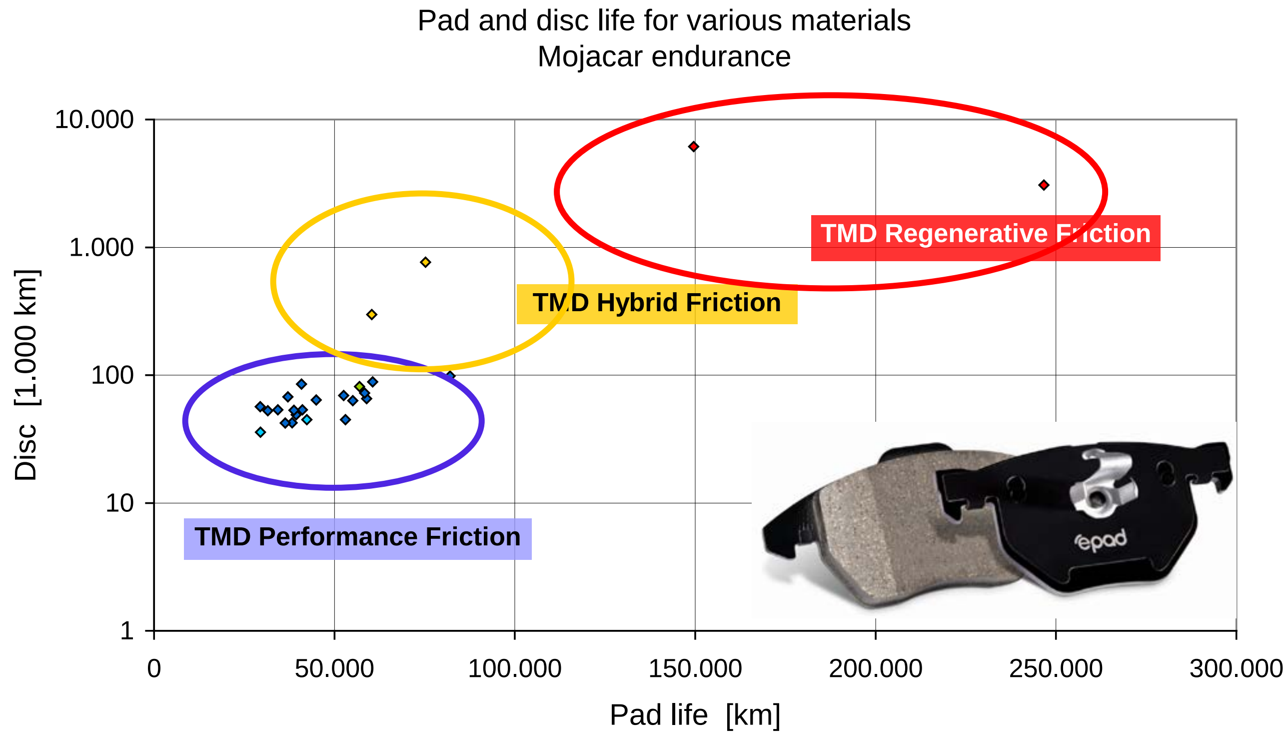
Friction material portfolio with performance characteristics:



- Friction products are build for purpose to suit customer and market requirements
- European style products (blue) target much more the brake power and higher speed driven aspects of brake performance,
- North American (red) and Asian style products are typically build for higher comfort, longer lifetimes compromising on lower friction levels

Friction solutions fit for purpose: lifetimes from 30.000 – 250.000 km

- TMD Friction provides a product range with a wide portfolio of materials fit for purpose
- Lifetimes of friction pads and discs are a consequence of the overall performance balance of the friction couple. Depending on the primary purpose, they can vary largely.



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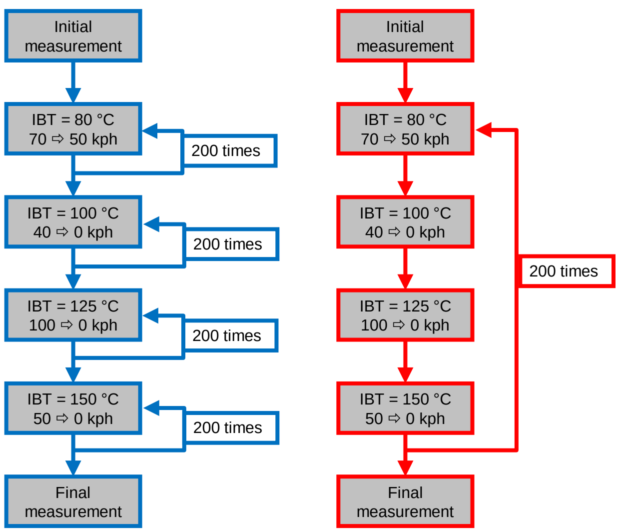
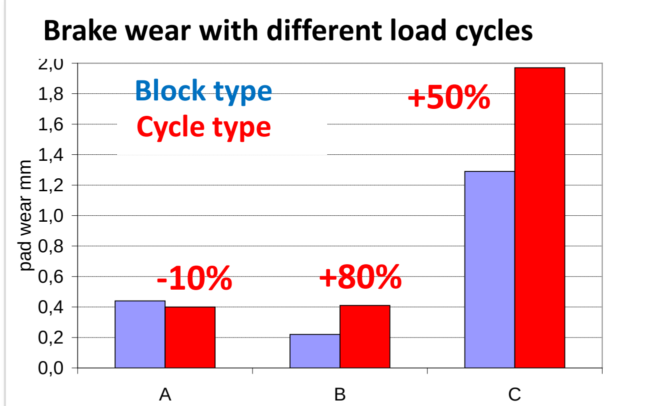
1. Brake load pattern history overrides load conditions

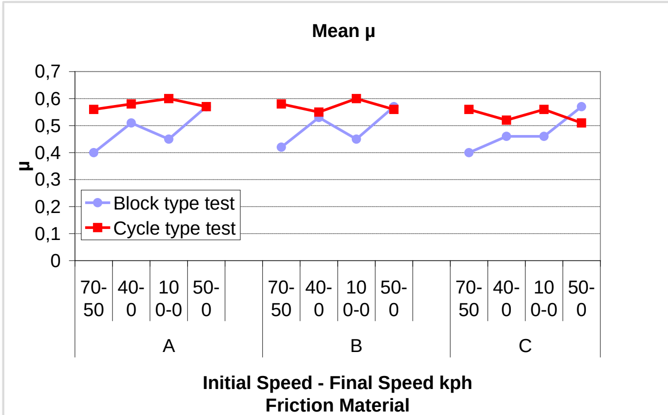
SAE Brake Colloquium 2009, Tampa, FL, 09BC-0065/2009-01-3027 - TMD Friction – R. Steege, G. Bauer, J. Lange, T. Holzapfel

Different tests applying identical brake energy but aligning individual brakings in a different sequence lead to different results!

Block type **Cycle type**







pad wear:

- Material A does not react differently
- Material B + C do react differently

mean µ:

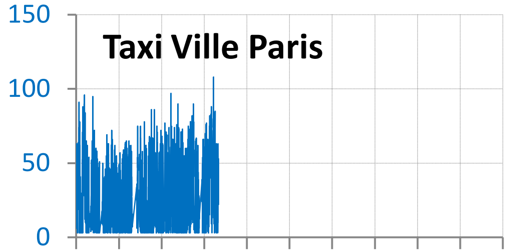
- **Block Type**
  A,B+C have a big dependency on ITB and speed
- **Cycle Type**
  less dependency

Block and Cycle type procedures do not allow any kind of lifetime prediction for brake linings at all.

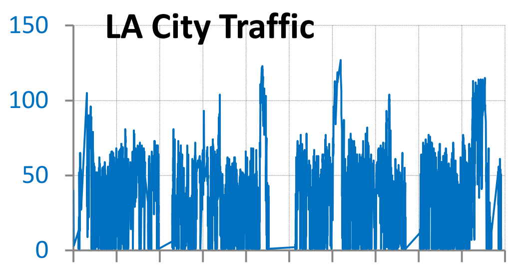
Conditioning of friction materials has a significant impact on wear results

2. Exemplary brake test patterns: speed profiles [kph] vs. time

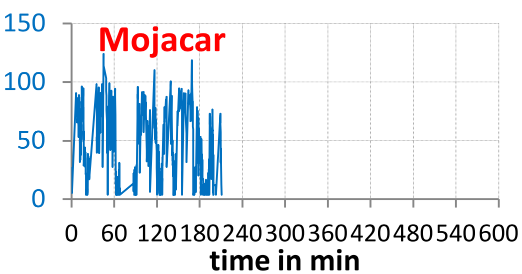
Vehicle speed over cycle time (brake test patterns)



duration	03:19:50
travel distance	178 km
brake applies	822
deceleration time	01:02:03
brake energy /kg	49.546 m²/s²

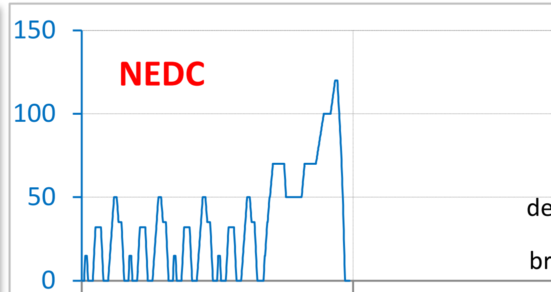


duration	**09:54:23**
travel distance	**328 km**
brake applies	**1496**
deceleration time	**01:57:19**
brake energy / kg	73.791 m²/s²

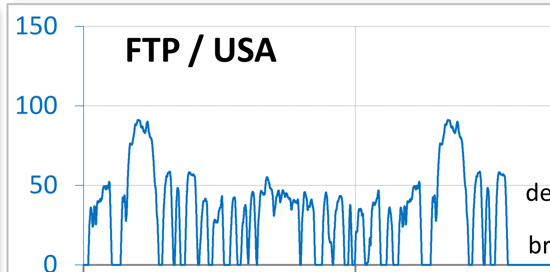


duration	03:30:37
travel distance	190 km
brake applies	338
deceleration time	00:11:52
brake energy / kg	15.580 m²/s²

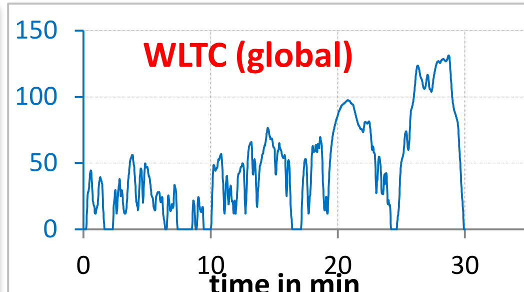
Vehicle speed over time (Typical fuel test patterns)



duration	00:18:50
travel distance	10,9 km
brake applies	17
deceleration time	00:03:02
brake energy / kg	1.218 m²/s²



duration	00:30:42
travel distance	17,8 km
brake applies	**111**
deceleration time	00:10:48
brake energy / kg	3.061 m²/s²

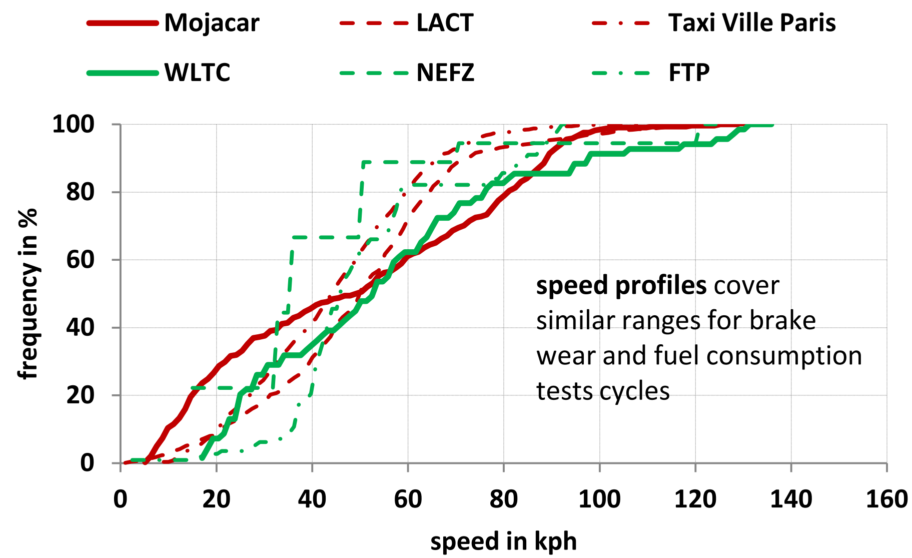


duration	00:30:00
travel distance	23,3 km
brake applies	68
deceleration time	00:01:11
brake energy / kg	3.514 m²/s²

3. Representatives: brake wear test pattern vs. fuel consumption pattern

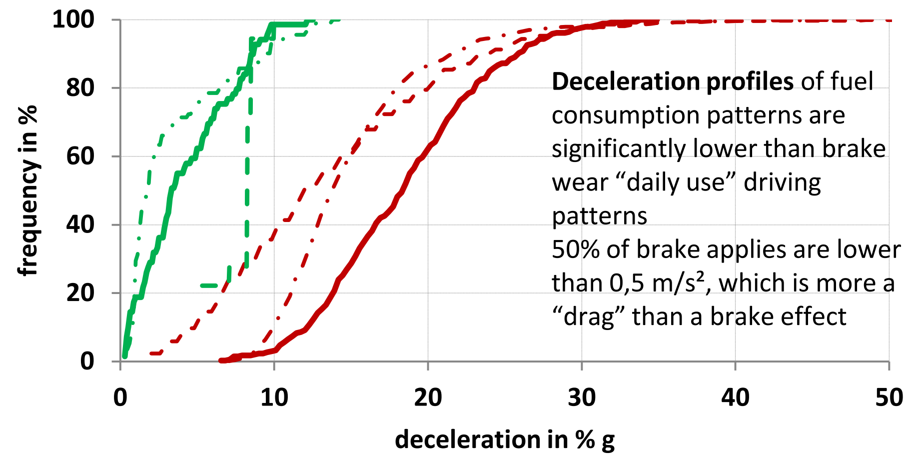
Brake wear patterns:

- Brake test patterns, especially Mojacar test driving patterns, are commonly utilised by OEMs to validate the NVH and wear performance of new cars
- Mojacar test patterns represent "daily use" considering speed and deceleration distribution, with dissipated energy lower than in "daily use" due to several slow driving sections used for NVH checks.
- Robust wear results call for long test schedules up to over 5000 km Mojacar or a full week 24/7 testing.

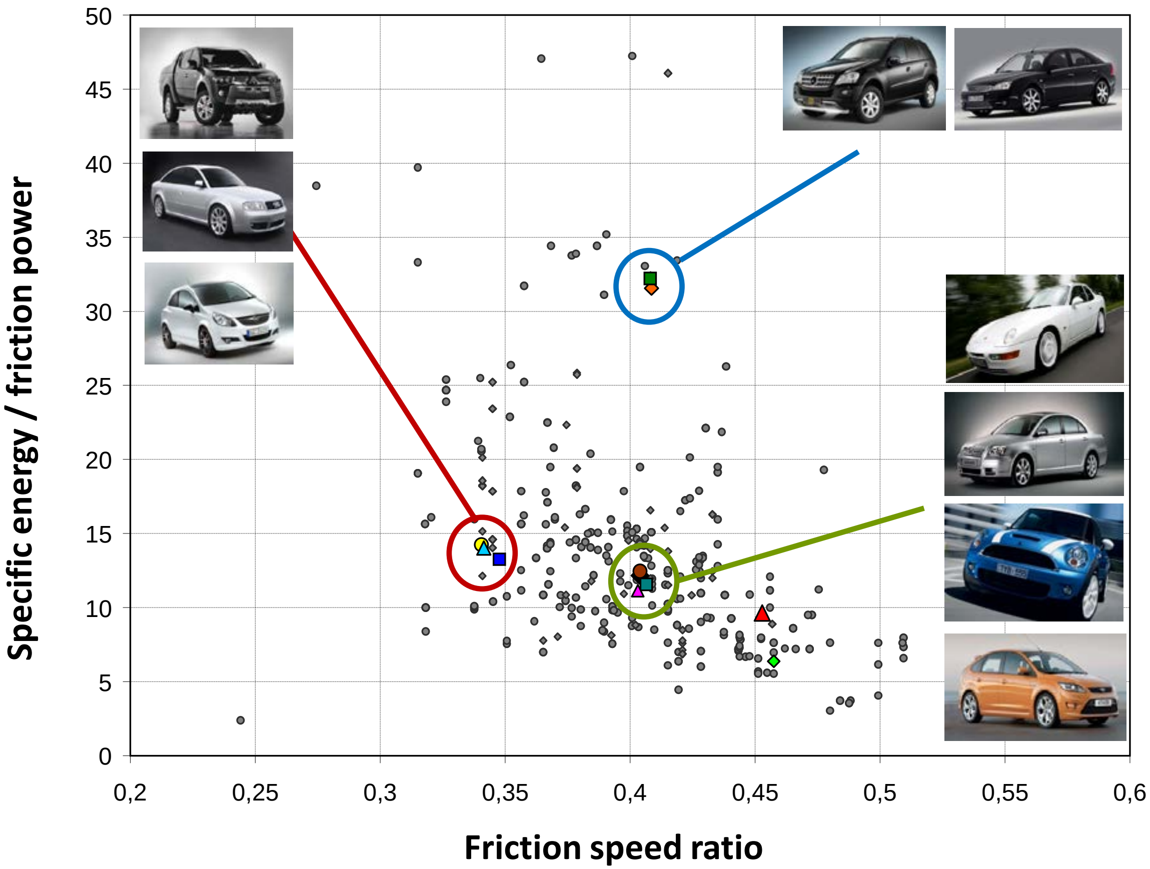


Fuel consumption patterns:

- Recent test pattern standards provide lower speed and much lower deceleration profiles than "daily use"
- Standardised fuel consumption results can be provided after ½ hour
- The WLTC approach is based on driving data collected with a global scope: fits "daily use" speed profile very well. The deceleration profile must be adjusted if brake wear shall be evaluated realistically



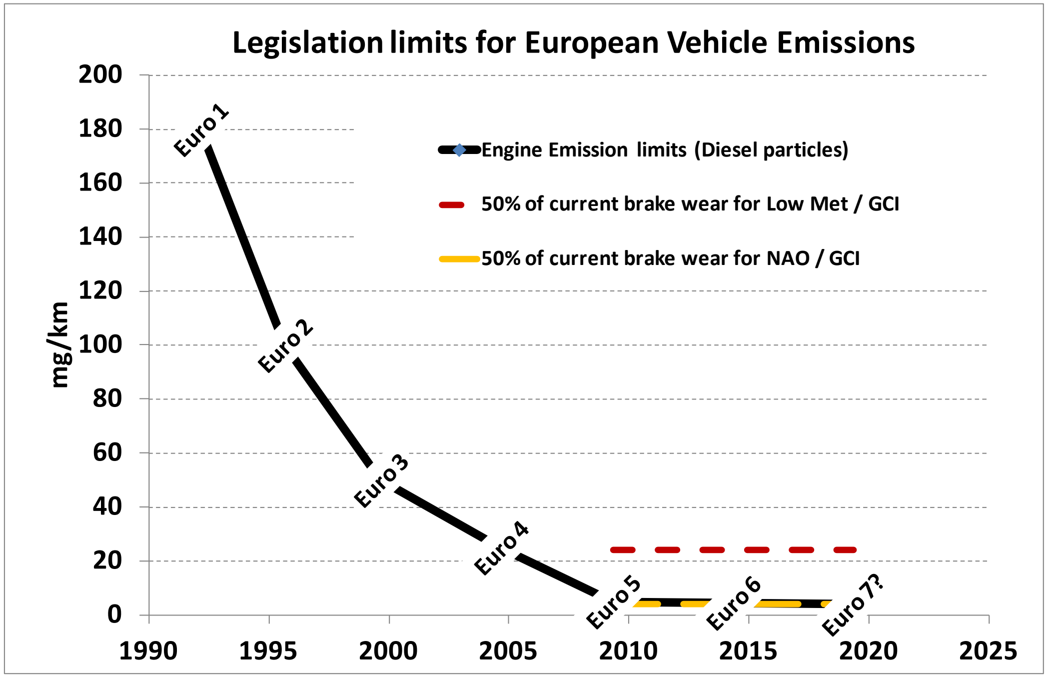
4. Brake designs result in different friction conditions for similar driving situations



- Vehicle and brake systems influence are significant driving secondary effects
- Depending on the primary influencing factors (speed and deceleration), vehicle and brake system design determine secondary effects that differ from car to car:
  - line pressure, friction surface pressure, rubbing speed and temperature at the friction interface are a consequence of the vehicle and brake design
  - Brake line pressure is just a consequence of weight, deceleration and system design

5. Results from Mojacar enforced brake testing compared to NEDC exhaust emission limits

- **Brake wear composed of brake pad and disc** wear debris generated during enforced endurance testing (Mojacar cycle) can be considered as maximum values for friction brake emissions.
- **Such primary friction brake wear** is related to the dissipated friction energy which will be reduced due to any means of recuperation.
- **Secondary dust capturing systems** would even more reduce wear particle amount before being released into the environment.
- **The friction wear numbers shown in the graph** are derived from enforced brake testing drive cycles. They cannot be compared to the limits for fuel consumption test cycles as the driving conditions are a lot different. However, they can indicate a maximum upper limit of what can be expected if such conditions would be applied and if 50% of the brake wear would become airborne.



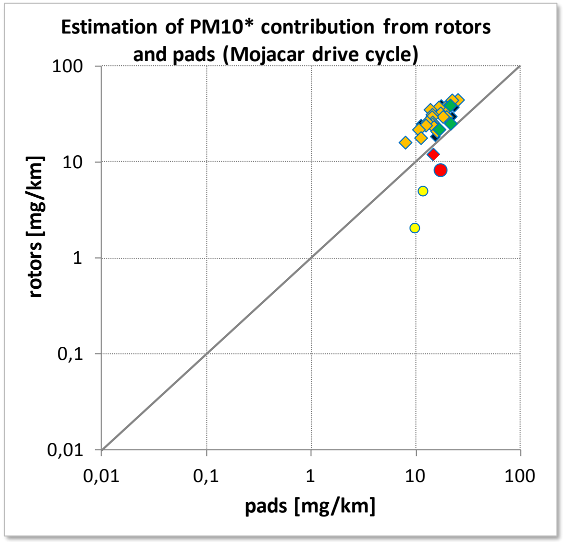
Range of vehicle emissions due to friction brakes utilisation

1) Measured wear rates lead to estimated airborne emissions under real driving conditions:
40% of the measured wear rates are regarded as PM10. *)

**) EC informal document GRPE-68-20: “50 % of brake wear particle mass becomes airborne, 80 % of these are* PM_{10}”

Results from all friction pairs in Mojacar test drive show:
- a maximum of 28 mg/km,
- **a median at 15 mg/km,**

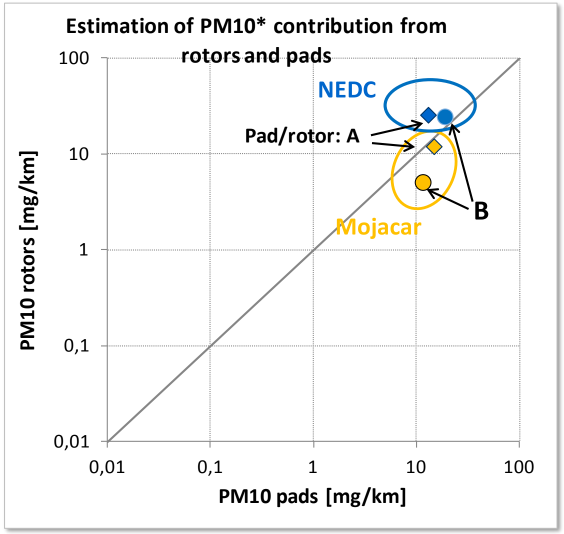
with 62% contributed from the rotors and 38% from the friction pads.



2) The drive cycle clearly influences the wear behaviour:
NEDC and Mojacar do not lead to similar wear results of wear ranges

Similar friction couples A and B, tested in the Mojacar drive cycle and the NEDC give a different range for the results

A reliable weight loss measurement on brake component level will need at least 20-40 cumulated NEDC cycles



Alternative measurement process:

A) Measurement of worn mass by **weighing pads and rotors**:
- \+ contribution of components available
- \+ achievable accuracy: 5-10 mg/km / 10 kg (component weight)
- \- dismantling effort
- \- adds noise: loss of debris

B) Measurement of worn mass by **weighing the full vehicle**:
- \+ simple
- \- necessary accuracy : 20 mg/km / 2000 kg (vehicle weight)
- \- overall value per vehicle only: brakes, tires, ...

Sanders et al., Environ. Sci. & Technol. 37 (2003) 4060

C) Measurement of **particle concentration**:
- \+ counts airborne wear only
- \+ allows for evaluating secondary measures
- \+ no dismantling effort
- \- overall value per wheel only: brakes, tires, ...
- \- equipment effort

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