Exploration of the impact of mineral fibers and calcium silicate on emissions of NAO disc pads using a simplified screening method for determining particle emissions

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Preamble

Euro 7 standards

- First standard worldwide to regulate brake emissions.

Implementation timeline

- **New Passenger Cars and Vans**: effective from Nov 29, 2026.
- **Existing models in production**: effective from Nov 29, 2027.

Measurement Protocol

- **UN-GTR24**: Protocol for measuring brake emissions in passenger cars.

Potential friction couple solutions for Euro 7

- **Coated rotors**
- **Brake Pad Development**: Innovations in Brake pad materials and formulations.

Lapinus Research Initiatives

- Friction material development/analyzing impact of mineral fibres.
- Impact of coated rotors, etc.

Research Objective

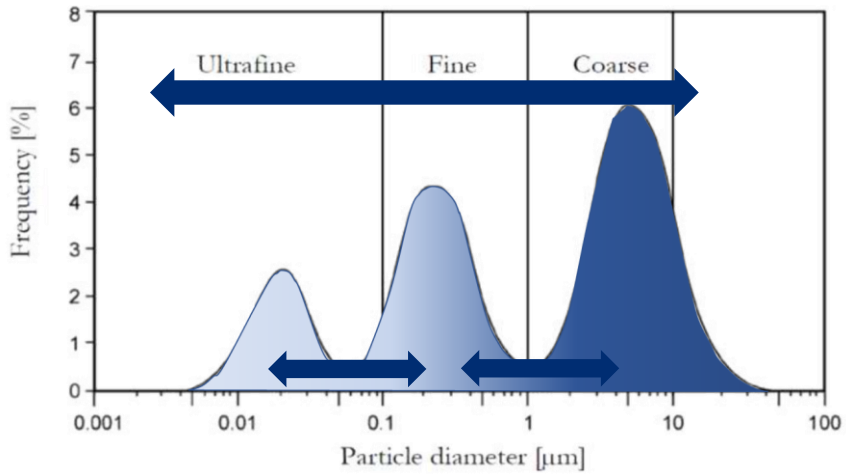
What?

Study the dependence of PN on:

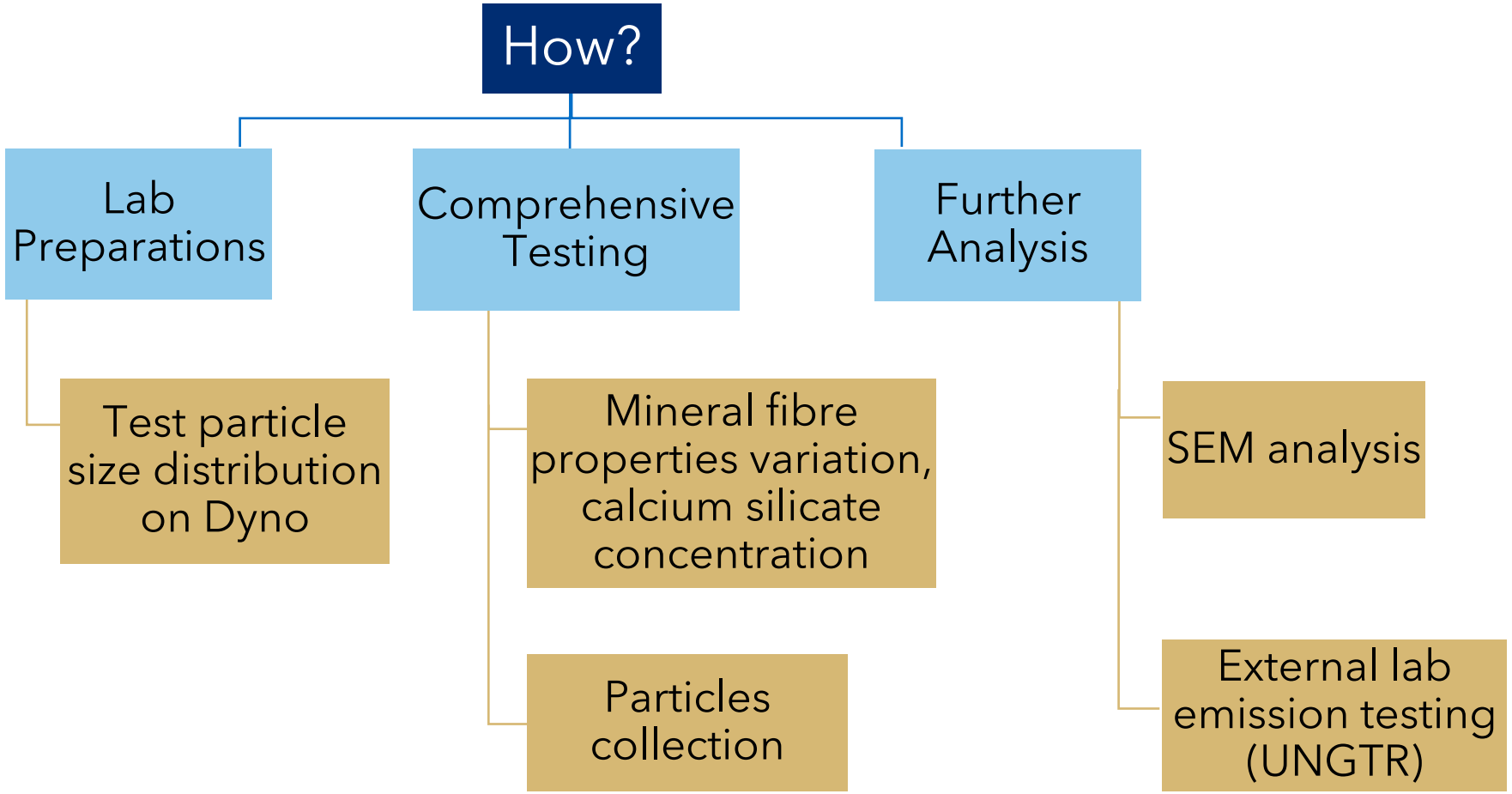
- Length, chemistry & concentration of mineral fibres
- Concentration of calcium silicate

Why?

- Euro 7 Regulation: Targets PM10 & PN
- Objective: Impact of mineral fibres & cal. sil. on emission



Research Objective



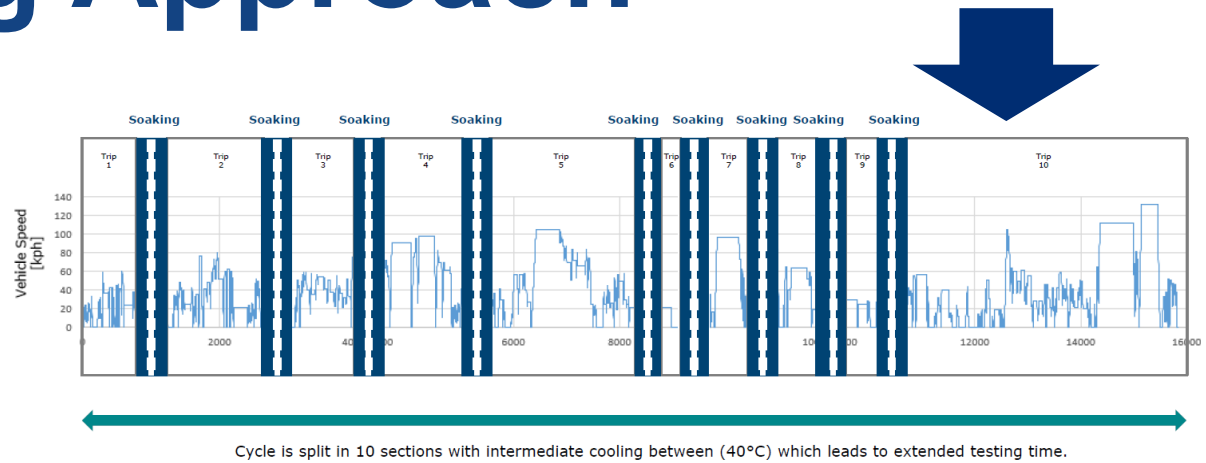
Challenges in Testing

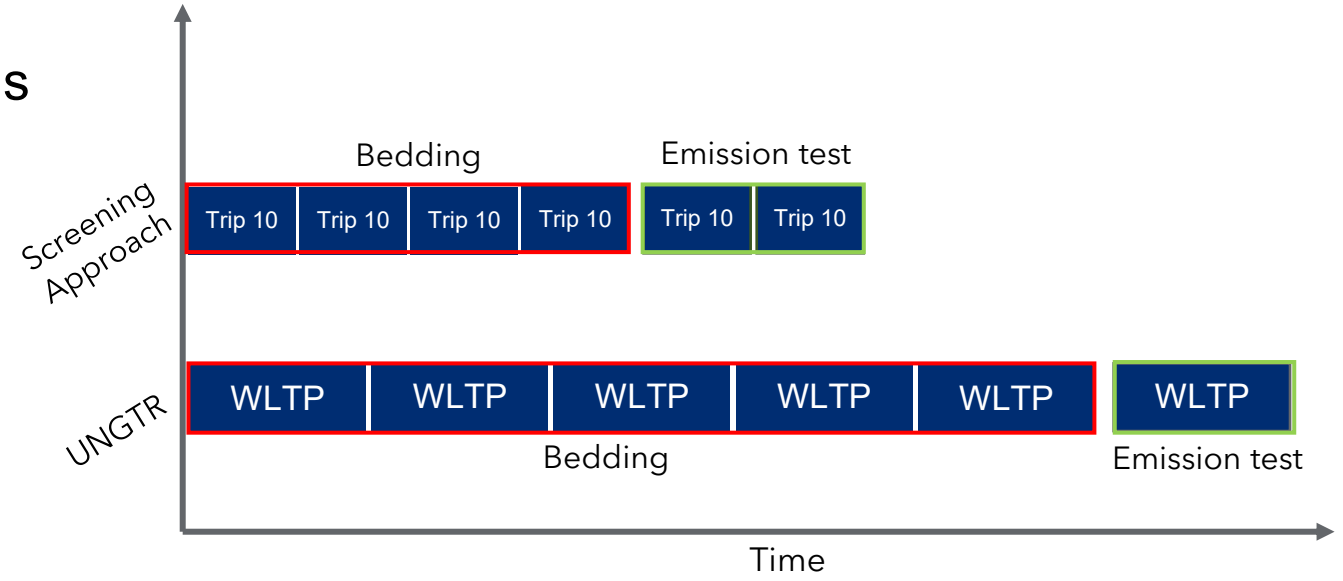
Screening Approach

UNGTR test method is expensive and time-consuming process	Efficient Methods: Simplified screening method to measure emissions efficiently in a R&D set-up	Simple cover for dyno as shown	Dekati instrument for measurement of particles	Samples for 14 different size fractions are collected

Testing: Screening Approach

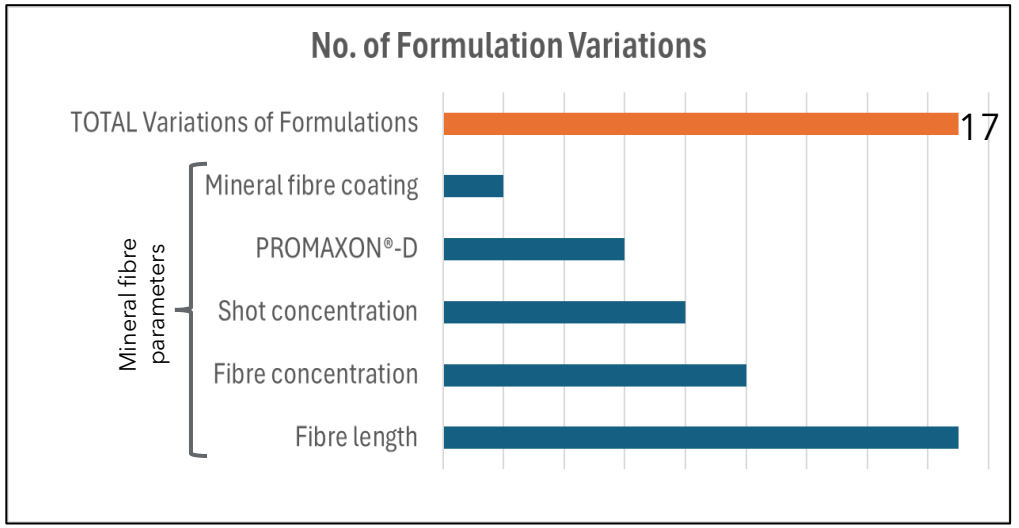
- Trip 10 of the WLTP is used
- Trip 10 consists wide range of driving scenarios, covering all the major requirements for emission testing
- Aids in evaluation of multiple formulations efficiently
- Time and cost saved while effectively obtaining the relevant data for R&D purposes





Testing: Formulations

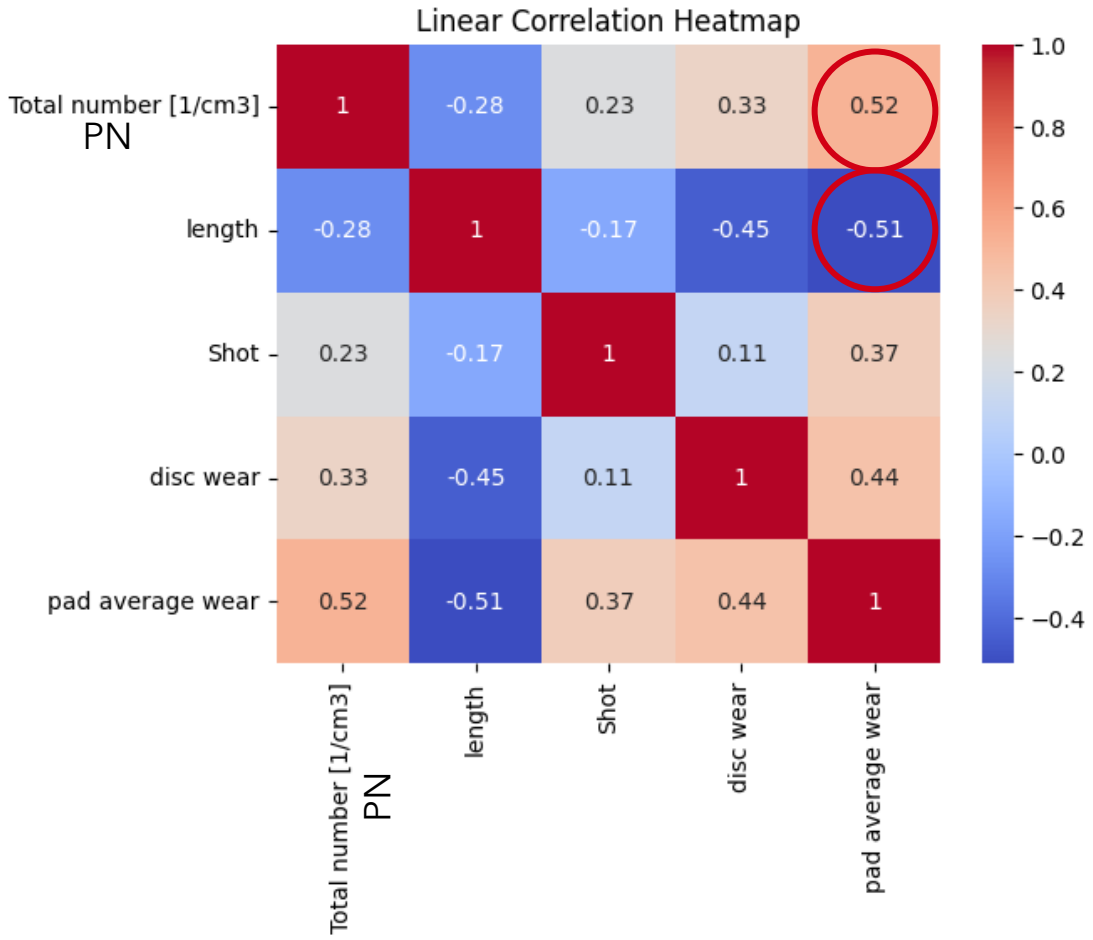
- 17 different brake pad formulations were tested
  - Fibre length, chemistry, shot level, coating are the variable parameters
- OE grey cast iron rotor used
- Trip 10 of WLTP is performed 4 times for bedding
- Trip 10 of WLTP is performed 2 times for emission analysis



NAO	Vol%
Resin	18
Friction modifiers	22
Lubricants	13
Lapinus mineral fibre	0-16
Calcium Silicate (PROMAXON®-D)	0-5
Aramid (Organic Fibre)	4
Fillers	22-43

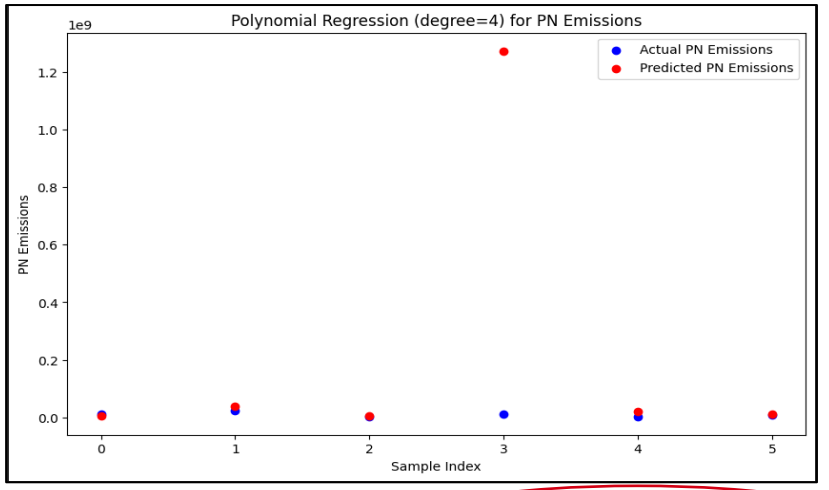
Results- Exploratory Data Analysis (EDA)

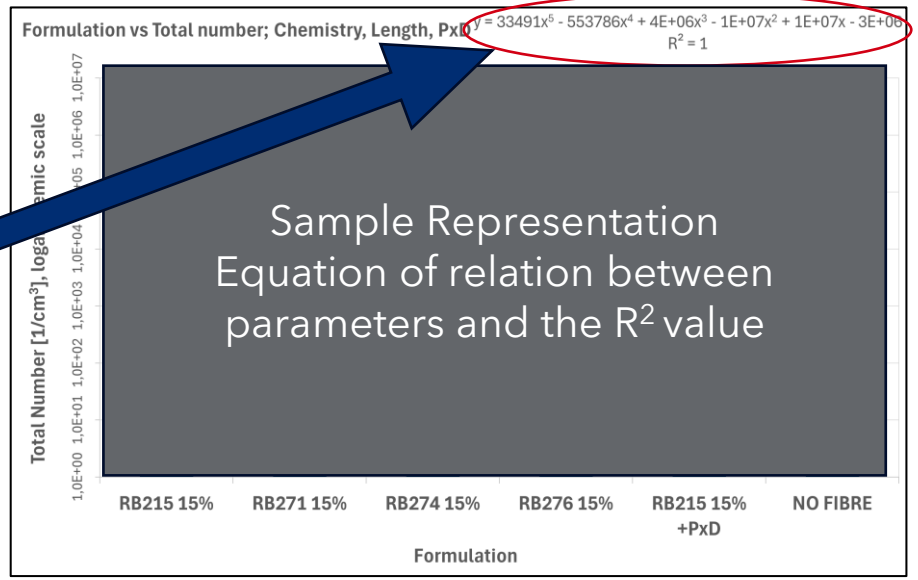
- A correlation heatmap is generated to visualize the relationships amongst all the parameters
- A heatmap is an effective tool for identifying relationships between different parameters, represented numerically on a scale from 0 to 1
- A relation between pad wear & PN(+ve indicating directly proportional) and pad wear & Length (-ve indicating inverse proportionality) has been observed
- The correlation is helpful in providing an initial idea and is used to further validate the initial findings



Results – ML based regression model

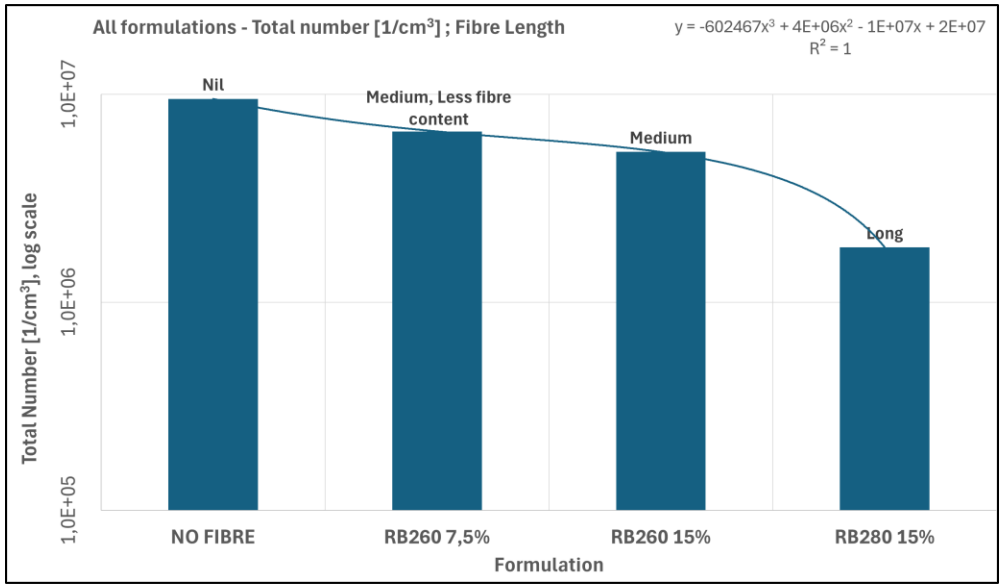
- To study the impact of brake pad composition on PN emissions, ML based data analysis technique is used
- Used linear and polynomial regression for predicting the PN emissions, in-turn also verifying the validity of the data collected and finding the relationship between different parameters
- R-Squared (R^2), indicates how much variance in the dependent variable that is explained by the independent variable in a regression model represented numerically between 0-1
- Polynomial degree of 4 has indicated very good correlation between length and PN (also explored later)

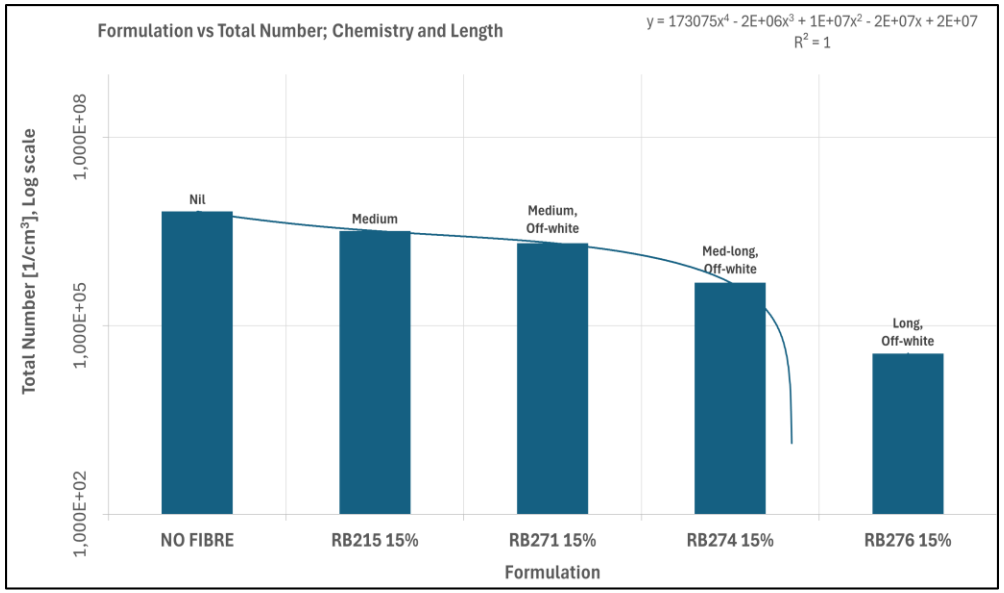




Results

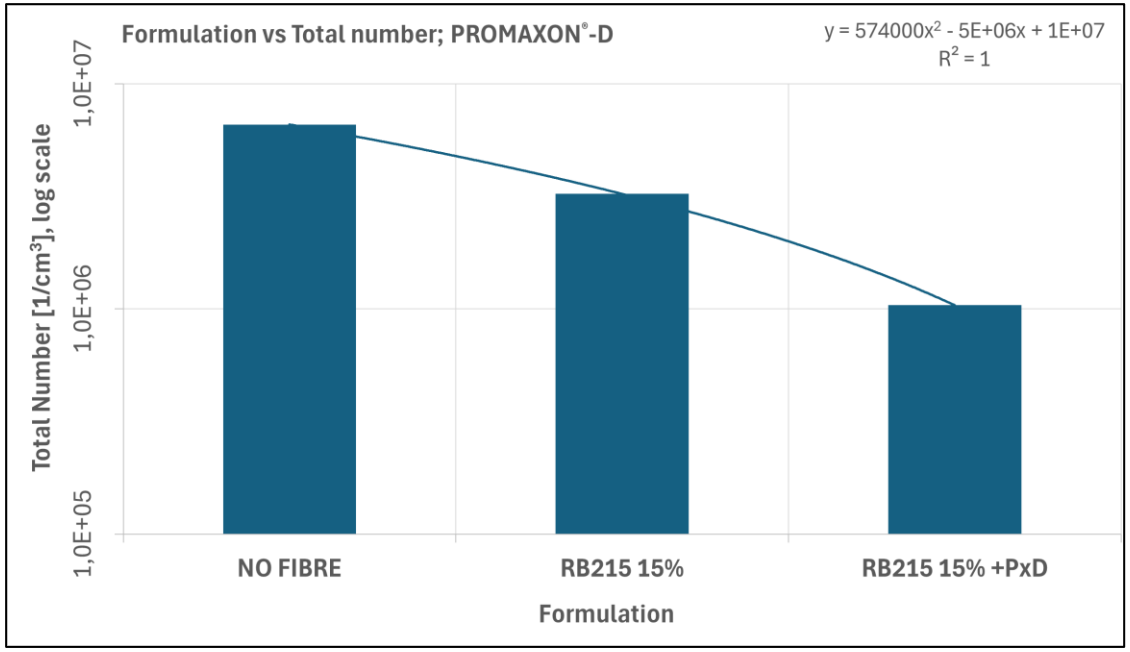
- Formulation vs PN is plotted with PN in logarithmic scale
- The length of mineral fibres does affect PN emissions
- The concentration of mineral fibres also has a positive impact on emissions
- It is noted that chemistry (off-white) of fibre also impacted emissions

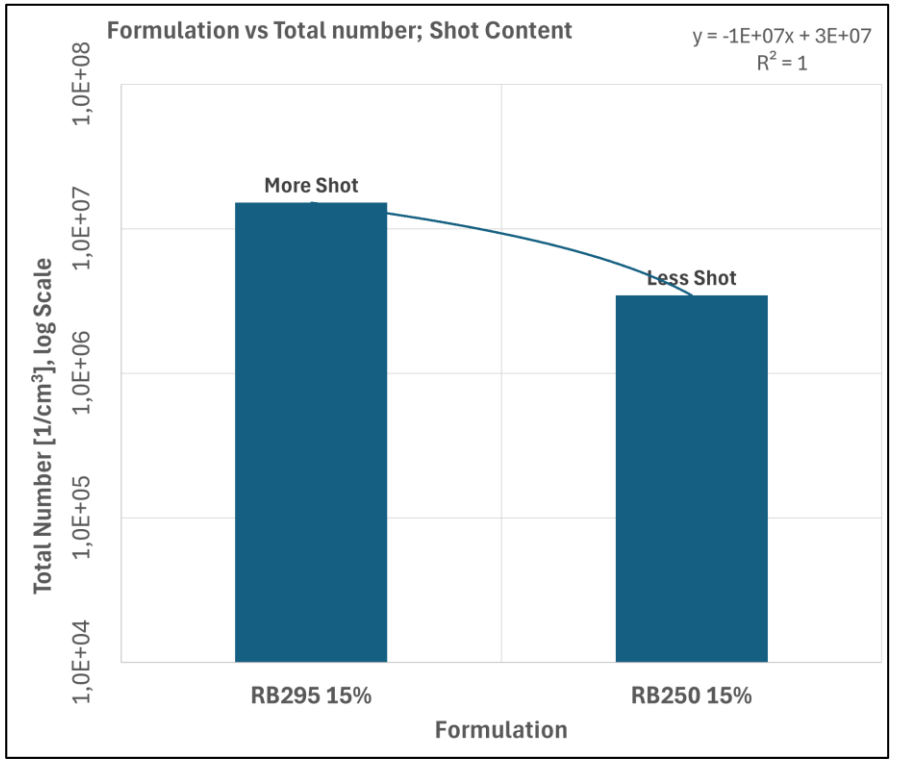




Results

- The addition of Calcium Silicate is observed to have a positive impact in reduction of PN (brake emissions)
- PN increases with increase in shot content





Conclusions

Screening Method
Efficiency: The simplified screening method appears effective for evaluating the impact of raw materials (mineral fibres and calcium silicate) on brake emissions, although future improvements are needed
Implications: Provides a quicker & cost-effective way to assess formulation changes, aiding in compliance with Euro 7

Conclusions

Observations
Presence of Lapinus mineral fibres have positive implications in reducing PN emissions
Length of mineral fibre also plays a role in reducing PN emissions, longer fibres performing better in general
Fibre chemistry is influencing PN emissions with the off-white fibres performing better than the grey-green fibres
Presence of **calcium silicate** (PROMAXON®-D) also has positive impact on PN emission reduction
As is expected, **shot content** is influencing the PN emissions and it is therefore essential to reduce the shot content

Conclusions

Outlook
Improvements in the experimental setup (hardware) is desirable for future work
Further Development of the experimental setup and the screening approach based on the learnings can increase consistency and the accuracy
Conducting official EURO 7 emission testing for comparison with our screening approach