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Development of Braking Profiles generating High Rates of Non-exhaust Particle Emissions of Vehicles

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Abstract

Mechanical frictions phenomena, related to the wear and the abrasion of tyres, brakes, clutch, and road surface, are responsible for significant particle emissions of the non-exhaust road vehicles which are considered as vectors of various toxic, carcinogens or mutagen substances. Their rate is high and the particles represent, today, major impacts on public health and on the environment. Physical characteristics of the non-exhaust road transport and surface emissions could be analyzed in a laboratory situation under controlled condition if suitable deceleration profiles and sampling systems are developed having the ability to increase the non-exhaust emissions. The aim of this paper is to develop the deceleration profiles, thus increasing the production rate of particles during urban, suburban, and highway driving conditions, allowing their identification and analysis. Experiments have been performed confirming the reliability of the developed braking profiles. A load effect, a large clustering, and the presence of isolated clusters and fibers have been observed. Size analysis indicated a high production of the particles in the range of [7 nm, 4 µm]. Further experiments and processing of data is necessary to confirm identification and quantification of the non-exhaust emissions taking into account atmospheric and turbulence features and the traffic.

Keywords: deceleration profiles, brake, non-exhaust emissions, fine and ultrafine particle sizes, size distributions, physical behavior, environment, air quality.

1 Introduction

In Europe, about 400,000 premature deaths attributable to air pollution occur each year. Non-exhaust road emissions are a significant source of particle emissions in cities affecting people and environment. While technological improvements have been achieved for reducing particulate matter (PM) emissions from vehicle exhaust, few actions are performed to reduce non-exhaust PM sources such as brake, road or tyre wear and road surface dust re-suspension. Their contribution is expected to increase in the coming years.

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In France, the non-exhaust road transport particle emissions have been assessed between 14 to 17% of the total particulate emissions in urban cities, and will further increase by 2020 (MEDDE, 2014).
Mechanical frictions phenomena, related to the wear and the abrasion of tyres, brakes, clutch, and road surface, are responsible for significant particle emissions of the non-exhaust road vehicles (Durbin et al., 1999, Ubanwa et al. 2003; Querol and al, 2004; Yan et al., 2011; Pant and Harrison, 2013). Their rate is high and they represent, today, major impacts on public health and on the environment.
Depending on their size, their density, their physical properties and their chemical composition, these particles are considered as vectors of various toxic, carcinogens or mutagen substances (Morawska et al., 2008; Löndahl et al., 2010; Uherek et al. ., 2010; Shi et al., 2011).. Whereas the exhaust emissions are largely studied, the non-exhaust ones have not been precisely measured so far, due to numerous difficulties related to their physical features, their particular dispersion phenomenon, and the use of a variety of vehicles and road surface materials…
In the vicinity of traffic control lights, emissions related to abrasion and resuspension are dominant in relation to exhaust emissions (Sanders et al., 2003; Iijima et al., 2007; Hulskotte et al., 2013). Their proportion within the particulate matter is increasingly high.
Two remarks can be made:
1. The lack of realistic driving braking profiles to assess the non-exhaust emissions in road transport is confirmed.
2. The development of representative driving braking profiles is needed with a methodology incorporating multi-levels of representativeness – road type, and the vehicle use.

The main first objective of this paper is a development of the braking profiles and sampling methods allowing to record and to analyze emissions of the non-exhaust particles. The second objective that this study is addressing will be the analysis of the physical and chemical characteristics of these PM and their evolution in the near fields. This could contribute to the reduction technological tools development and policy recommendations. Finally, the recorded data will be useful for the validation of the existing models of the non-exhaust particle dispersion.
The next sections describe the development of the braking profiles, the preliminary results, and a conclusion with remarks and prospectives

2 Braking Profiles

The braking profiles consist of a succession of braking in order to represent a realistic driving condition. Driving cycles, existing in the open literature, based on a statistical studies of different driving conditions (Montazeri-Gh, M. Naghizadeh, 2003; Tsai et al., 2005), have been used: urban, rural and highway cycles. In this study, the urban, rural and highway cycles have been processed allowing to build the new braking profiles.
For example, figure 1 (A, B, C) shows the Real Driving Cycles, as Artemis driving ones, that have been used in this paper (Tsai et al., 2005; Boulter and McCrae, 2007-10; Livia Della and Meccariello, 2016) to perform the braking profiles.
The hard and light decelerations of the vehicle have been extracted from the previous cycles to obtain the three braking profiles corresponding to an urban, a suburban and a

highway trips. Figure 2 gives the obtained results processed by using a suitable statistical analysis (Lin and Niemeier, 2002; Knez et al., 2014).
Another way to develop new braking profiles of real driving conditions consists in generating brakings by -50 km/h over 5 sec which start at 130 km/h. Figure 3 represents this behavior idea with stages, with a duration of two minutes each, occurring respectively at 130 km/h, 80 km/h and 30 km/h.

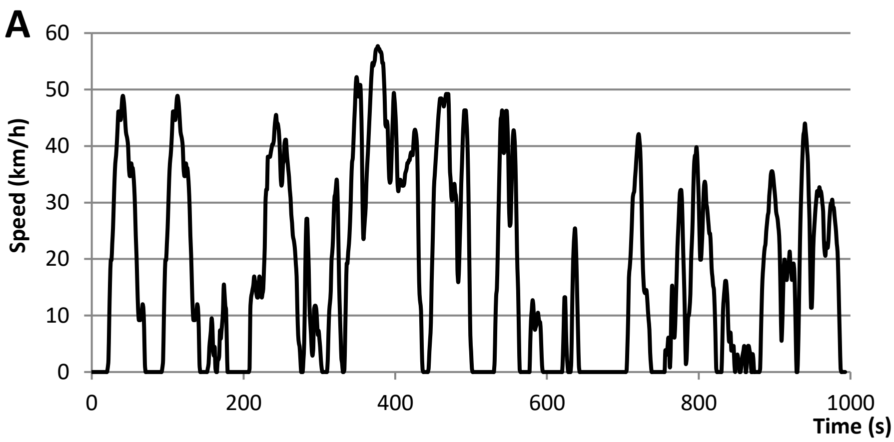
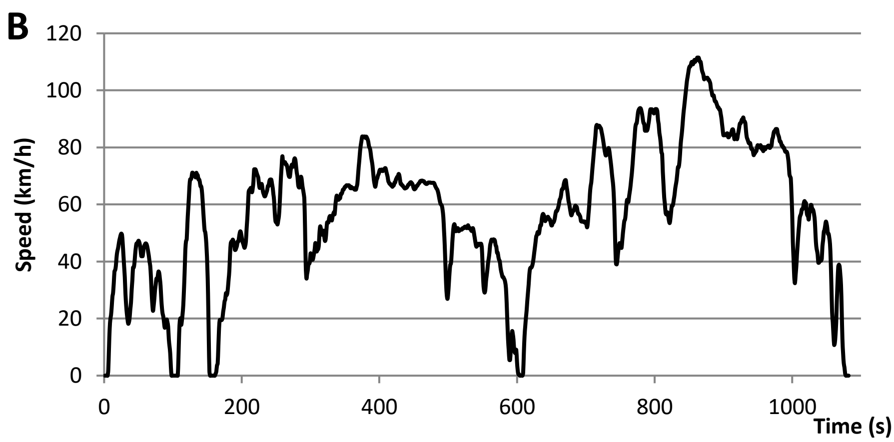


Figure 1: Artemis driving cycle: A) Urban (Boulter and McCrae, 2007-10)



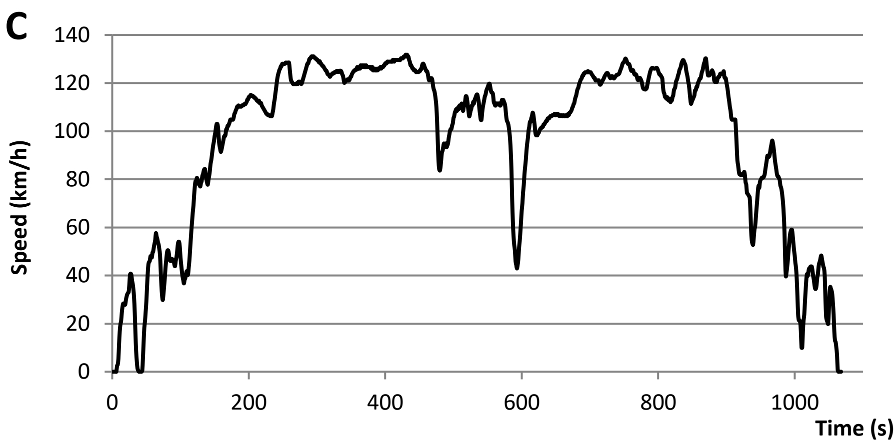
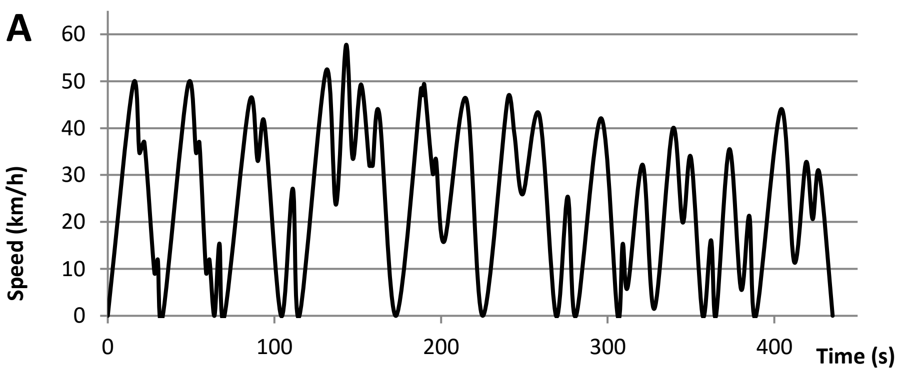


Figure 1: Artemis driving cycle: B) Suburban - C) Motorway (Boulter and McCrae, 2007-10)

Because the braking profiles given in the previous figures (figures 2B, 2C and 3) were very short and were not in favor of the non-exhaust particle emissions high rate, these sequences were reproduced several times as indicated in the following figure 4. For the suburban braking, its sequence was repeated twice, three for the highway, and four times for the "step by step" profile. These sequences are the selected profiles which have been tested on the roller bench in laboratory and controlled situations. It should be remembered that the work has been carried out without ventilation of the engine and using an extraction of the exhaust emissions outside after filtration. The number of the used sequences has been chosen versus the high degree of temperature of the engine occurring during our tests: between 200 °C and 650 °C.



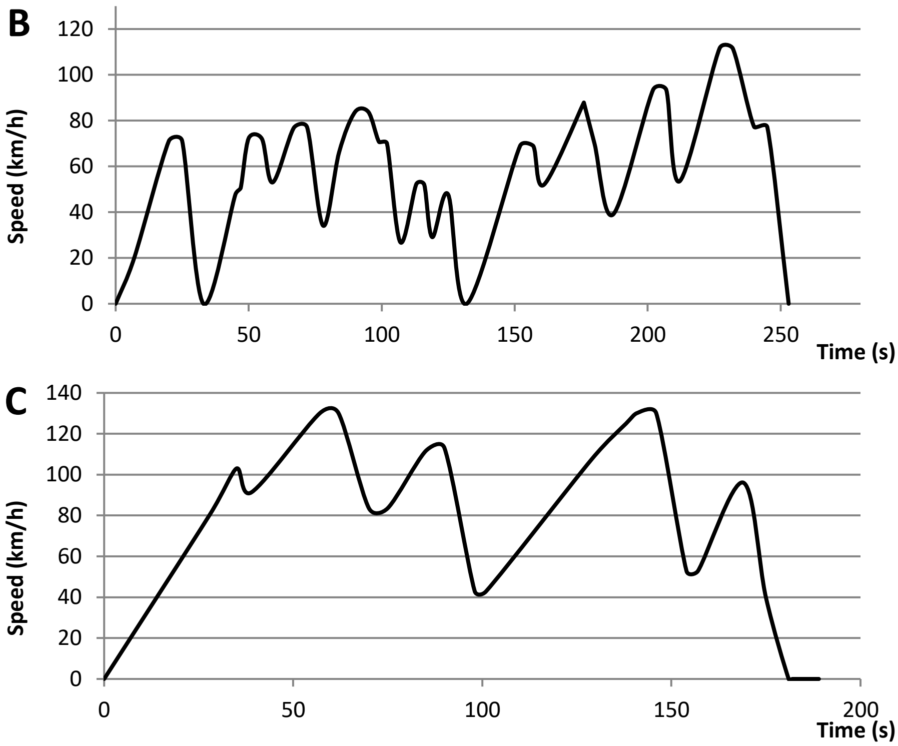


Figure 2: Braking profiles extracted from decelerations in the previous cycles given in figure 1: A) Urban area - B) Suburban area - C) Motorway area

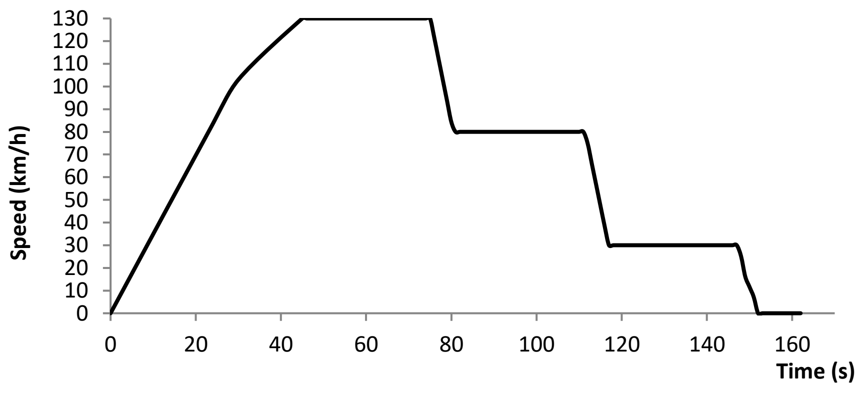


Figure 3: Step by step braking profile (-50 km/h over 5 seconds - Khardi, 2017)

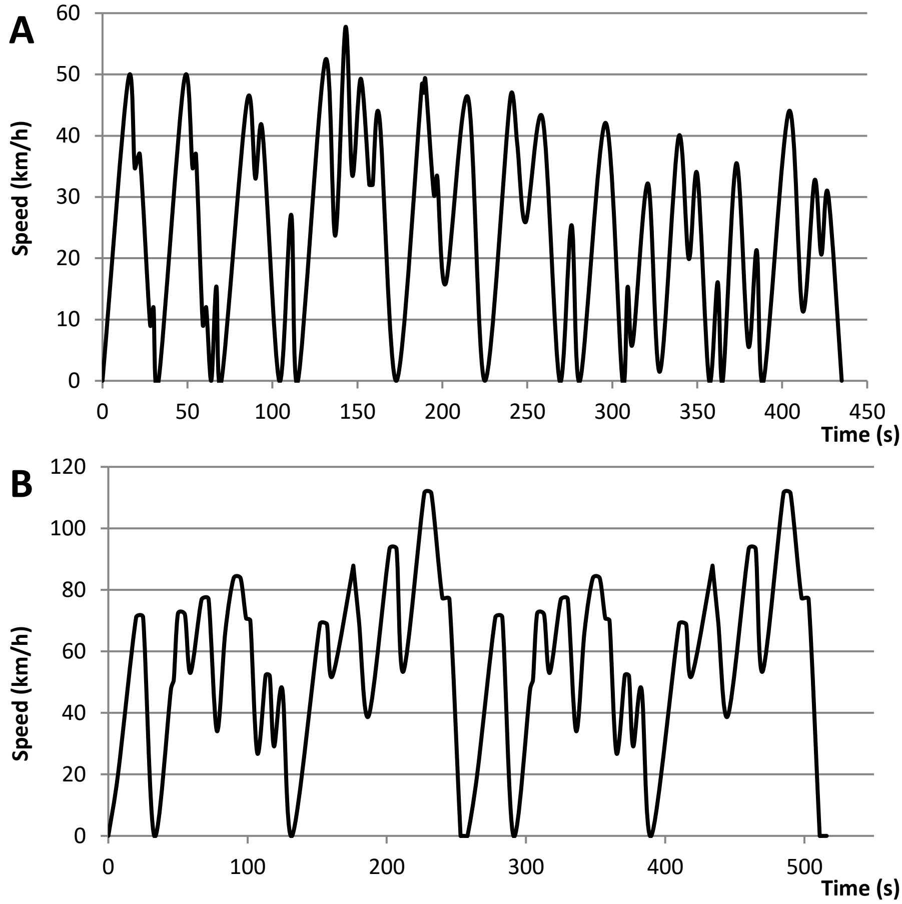
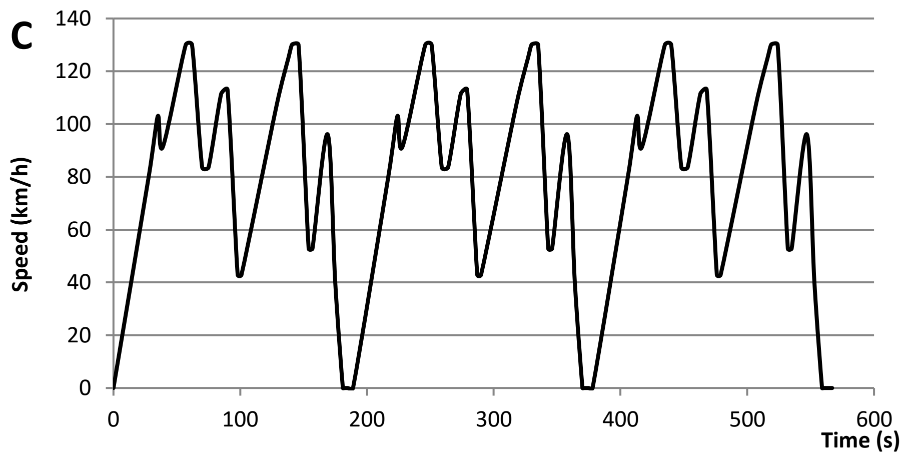


Figure 4: Braking profiles
A) Urban area - B) Suburban area)



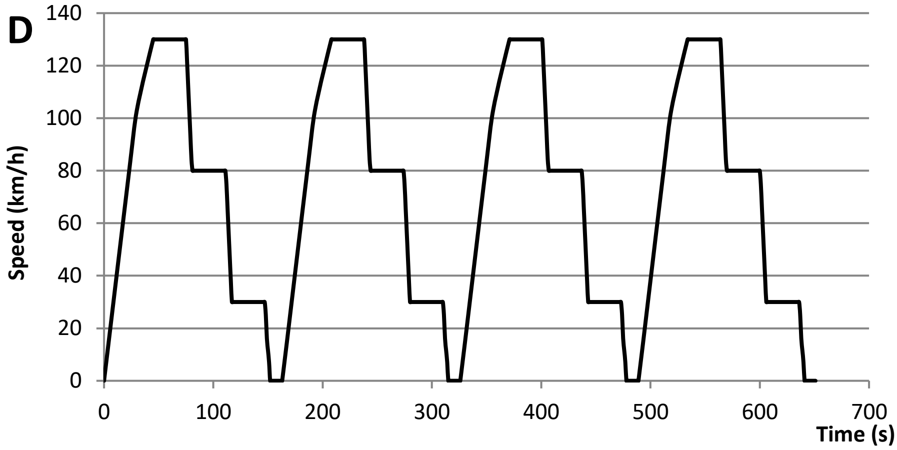


Figure 4: Braking profiles
C) Motorway area - D) Step by step (-50 km/h over 5 seconds)

3 Preliminary Results

Preliminary tests of these new braking profiles (Khardi et al., 2017) confirmed two major phenomena: metal wrenching and abrasion. As shown in figures 5, 6 and 7, Using the Keyence microscope and MEB, clusters, fibers, large metal dimensions, and in particular a high rate production of non –exhaust particles, having sizes between 7 nm and 4 µm, were observed.

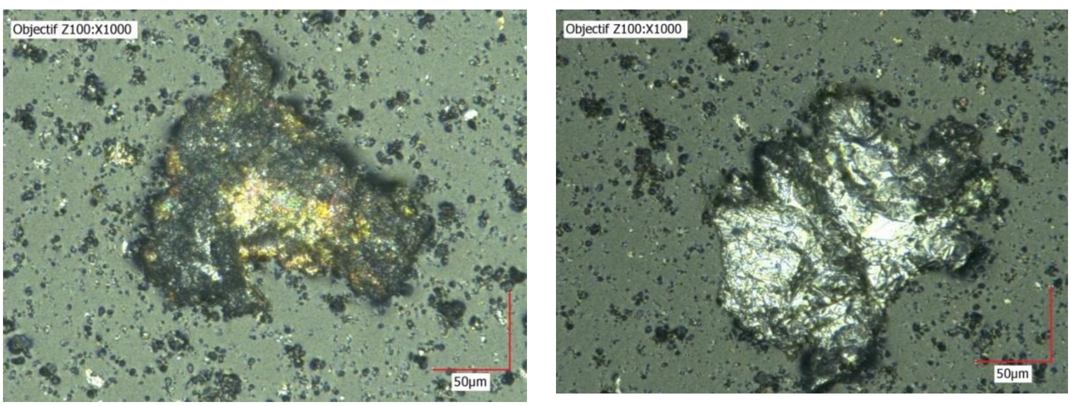


Figure 5: Surface metal removal and wrenching during braking on highway

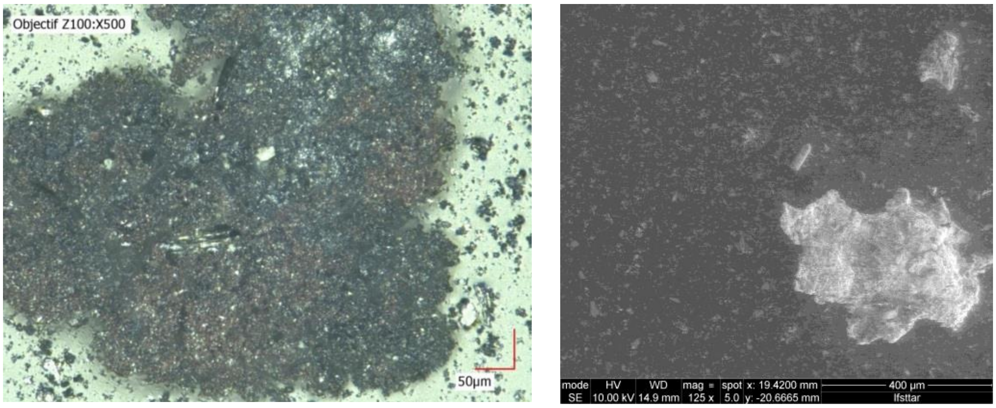


Figure 6: Particle clustering observed during highway braking profile (Kayence and MEB)

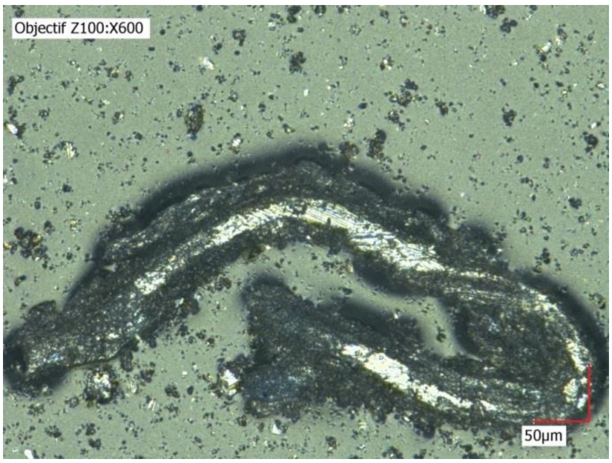


Figure 7: Fiber elements observed during highway profile

Further analysis has to be performed to complete these preliminary results on the non-exhaust emissions. Experimental set-up, the sampling system of non-exhaust emissions, the recorded data related to granulometric studies, identification of non-exhaust particles and analysis of their physical and chemical behavior are needed and will be carried out.

4 Conclusion

The lack of braking profiles allowing the production of a sufficient rate of the non-exhaust particles for their deep analysis and identification is a key challenge in a development of knowledge related to this scientific topic. Those profiles are a critical gap that warrants urgent action and recommendations in terms of reduction technology and system. Four braking profiles (urban, suburban, highway and step-by-step) covering in-depth study of data collection methods have been formulated.

The main objective reached in this paper is a development of braking profiles making possible a high level of the non-exhaust particles emitted by the brakes, in a sufficient quantity. Two technics have been used allowing the implementation of new braking profiles:

1. Based on the existing driving cycles which are well representative of the driving conditions (urban, suburban, highway), deceleration distribution to define those profiles have been used.
2. A non-common method called "step-by-step method" has been developed. It considers fast decelerations of 50 km/h at each stage and lasting two minutes at speeds of 130 km/h, 80 km/h and 50 km/h.

Preliminary tribological analysis showed a load effect of particle production, a large clustering, and the presence of isolated clusters and fibers. Size analysis indicated a high production of the non-exhaust particles emitted by the brakes in the range of [7 nm, 4 μm].

Further experiments and tests are needed to confirm the analysis of the produced non-exhaust particles (concentration, number, and size), their behavior, their physical and chemical features in the near field.

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