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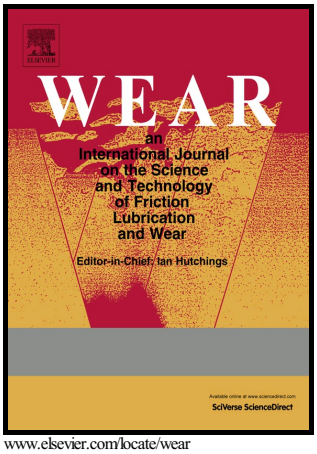

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A novel real-world braking cycle for studying brake wear particle emissions

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Abstract
Until now, a wide range of braking conditions has been applied in non-exhaust emissions related studies. This often led to incomparable results and contradictory conclusions. Furthermore, there is no industry-wide accepted brake cycle available that represents real-world braking conditions.
In this study a novel braking cycle is presented aiming towards a commonly accepted methodology for sampling and measuring brake wear particles. The cycle is based on the WLTP reference database, which includes in-use driving data from five different world regions with a total mileage of 740,000 km. The cycle development and statistical match to the WLTP database is presented. Experimental testing of the cycle both on the brake dynamometer and vehicle level are shown. Brake disc temperature behaviour on the real vehicle and dynamometer level is compared. It is shown that below a disc temperature of 160°C, particle number emission is at background and sharply increases at brake temperatures above.

1. Introduction

Research on brake wear particle emissions is still at its infancy. For some aspects, existing literature data are sufficient to draw conclusions: For instance, results have shown that approximately 40 % to 50 % of brake debris becomes airborne, while the remainder is being deposited on the road [1, 2]. Mass size distributions of brake wear PM_{10} have been typically reported to be unimodal with the peak varying between 1 µm and 5 µm [3, 4, 5, 6]. Depending on the conditions of the braking event – and particularly on the temperature reached by the braking system – ultrafine particles can be emitted [7, 8, 31]. Finally, there is agreement that brake wear PM_{10} emission factors of 4-10 mg km^{-1} $vehicle^{-1}$ can be considered typical for passenger cars [3, 6, 9, 10].However, a more accurate calculation would require well-defined testing conditions.

1.1 Lacking knowledge on brake wear particle emissions

There are many other aspects for which the published data are not sufficient to reach sound conclusions. The most important findings of a literature study conducted by the Joint Research Centre in 2015 [11] showed that:

- There is a lack of data regarding the actual contribution of brake wear particles to ambient PM_{10} and $PM_{2.5}$ concentrations. Source apportionment studies appear to be inadequate due to the lack of specific unambiguous tracers that can be used for brake wear. Further to that, brake particle emissions are highly variable and depend upon different conditions including also environmental conditions.
- Particle number size distribution of brake wear has been reported to be unimodal [10], bimodal with both peaks lying at the fine size range [12,13], bimodal with one peak being at the fine and one at the coarse size range [14], as well as multimodal [15], with peaks both at the fine and coarse size. It is clear that particle number size distribution of brake wear is highly variable and depends upon testing conditions.

In many cases the results reported in the literature are not consistent – or even are contrasting – as a consequence of the application of different testing methodologies, measurement techniques and