Review of Tires Wear Particles Emission Research Status

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Abstract. Tires are the only components of the vehicle that direct contact with the ground. Tires act as the roles of the vehicle loading, driving and steering and so on. In the process of driving, the small particles will generate from the wear between tires and ground that are released to the atmosphere, soil and river. Considering tires wear principle, test methods, environmental effect and the working process of UN WP29 GRPE PMP group, this article give the summary and analysis. This article will briefly describe the generation and physical characteristics of tire wear particles, also include the test methods, transportation path and environmental effect.

1. Introduction
Since the new century, the number of vehicles in China has increased rapidly, especially the rapid development of new energy vehicles, but vehicles emissions directly affect the public health. Automotive emissions are divided into exhaust emissions and non-exhaust emissions: exhaust emissions, with long-term in-depth research and legislative management, has been widely known; Non-exhaust emissions, mainly including the wear particle emission of tires and brake lining, belongs to a new research field in a certain sense, and there are relatively few studies at home and abroad [1, 2]. According to the research, tire wear, lining wear, road dust and other non-exhaust emissions can account for 50% of the PM in the air under certain conditions [3]. Tire wear particles (TWPs), which are tiny particles generated by the friction between tires and the ground during vehicle running, are an important part of non-exhaust emissions and an important source of atmospheric particles. For new energy vehicles, vehicle exhaust emissions are significantly reduced, even to 0 (pure electric vehicles), so non-exhaust emissions are particularly important [4]. This article focuses on tire wear particles, considering the research status of UN WP.29 GRPE PMP (World Forum for Harmonization of Vehicle Regulations Working Party on Pollution and Energy Particle Measurement Program Informal Working Group), brief introduces the tire wear particle emission characteristics, research status at home and abroad.

2. Tires Wear and Particles
The tyre is a complex elastic rubber product that is the only part of a vehicle that comes into contact with the ground. A tire structure mainly includes tread, tire shoulder, tire side, belt ply, cord ply, inner lining, etc., as shown in figure 1. The wear process of tires is relatively complex, but there are three main influencing factors: tire factors (structure, material, wear resistance, etc.), vehicle factors (suspension parameters, load, speed, driving force, etc.) and environmental factors (road conditions, temperature, driving habits, etc.). The rubber wear principle is very important for the study of tire wear particles generation that need to be studied. In the field of tribology, rubber wear mechanism research has been relatively mature, including fatigue wear, friction wear, adhesive wear and chemical erosion
wear [5, 6]. In the process of driving, the tires are in direct contact with the ground, and support vertical, lateral, tangential load and reversing, capsizing and rolling resistance moment when a vehicle is steering, braking and driving. In the contact process between tires and ground, there are direct friction and slippage, which causes micro-cutting and tearing between tires and road surface. In this process, the wear between tires and ground exist for all the time. When the accumulated friction energy of a local volume in the contact area reaches to the failure energy (critical value) of the tire surface in the contact area, the local volume will be removed from the surface in the form of abrasive chips [7, 8], namely, wear appears. However, tires wear usually does not exist in a single form, but in mixed wear between tires and road surface, each accounting for about 50% [9].

Figure 1. The structure of a tire.

The tire wear particles will be released into the air, road surface, soil, or rivers. Figures 2 and 3 are the physical characteristics of wear particles. According to the research of PMP working group [9]: the diameter of tire and road wear particles (TRWP) is mainly distributed in 4-350 μm with an average diameter of 100 μm, which is larger than the volume of PM2.5 (≤ 2.5 μm) and PM10 (≤ 10 μm) (figure 4). The density of particulate matter is about 1.8g/cm³, which is bigger than the density of water (1.0 g/cm³).

Zhang [4] carried out a research on tire wear particles through the test bench simulation technology. Regarding the number of particle size distribution, the number of tire wear particles is mainly ultrafine particles, with the maximum concentration below 100nm. Regarding the mass of particle size distribution, the mass of tire wear particles is mainly fine particles and coarse particles, and the maximum concentration are 0.5 μm and 1.3-2.5 μm. Similarly, Mathissen [10], Dall’osto [11], Kwak [12, 13] and others all used different test methods to study the particle size of tire wear particles and got different or similar test conclusions.

Figure 2. The characteristic of TRWP.
3. Wear Particles Emission Test Methods
The testing methods of tire wear particles emission mainly include laboratory test (test equipment is shown in figure 5) and road test. Currently, there are only ISO standards of testing methods for this area, as shown in table 1.

According to the PMP working group, Japan JASIC (Japan Automobile Standards Internationalization Center) developed a particle emission measurement method of passenger vehicle tires. In this method, on the basis of six-component force measurement vehicles, particle sampling, filtration, counting and other devices are added to study the relationship between vehicle lateral acceleration and tire particle emission. Based on thermal cracking and GC analysis, the quantitative measurement of particle emission is realized, and then calculated the emission factor [14]. The structure of the test device is shown in figure 6. At last, the study concluded that tire particle contributed about 3% of the PM2.5 in the atmosphere, with most of the rest falling on roads.
Table 1. ISO standards.

| Number | Standard No. | Standard name | Standard version |
|--------|--------------|---------------|------------------|
| 1      | ISO/TS 20593 | Determination of the mass concentration of tire and road wear particles (TRWP)—Pyrolysis-GC-MS method | June 2017 |
| 2      | ISO/TS 21396 | Determination of the mass concentration of tire and road wear particles (TRWP) in soil and sediments | December 2017 |
| 3      | ISO/TS 22638 | Generation and collection of tyre and road wear particles (TRWP)-Road simulator laboratory method | July 2018 |
| 4      | ISO/TS 22640 | Framework for physical and chemical characterization of tyre and road wear particles (TRWP) | July 2018 |
| 5      | ISO/TS 22687 | Framework for assessing the environment fate of tyre and road wear particles (TRWP) | August 2018 |

Figure 6. The measurement device.

Kwak used vehicle road test method and laboratory simulation test method to investigate the physical and chemical characteristics of ultrafine particles emissioned from vehicles. In this study, under the conditions of constant speed, braking and turning, the emissioned particles at the right front wheel of the vehicle was collected and analyzed. There two collection points, 40 mm and 90 mm far away from the ground. Figures 7 and 8 respectively show the test method and test principle.

In China, there is little research in this field, but as the government to strengthening regulation and air pollution in all areas of concern, some research institutions (Beijing Environmental Protection Science Research Institute [3], China Automotive Technology Research Center Co., Ltd. [4], etc.) and colleges (Nankai University [4], Ningbo University [15], etc.) are also carried out related research. Based on the test simulation bench for the first time in China (as shown in figure 9), Zhang Jing conducted research on tire wear particle emissions, involving tire speed, load, slip angle, camber angle of the single and complex influence factors, studied and analyzed the number and mass of particle emission concentration, also include the composition of the particles.
The test equipment is external drum test device, and the drum shell is the same as asphalt road surface to imitate the real road. According to the study, the emission of tire wear particles is mainly ultrafine particles, with the diameter of 6 nm-10 μm particles accounting for about 94.80%. There were at least two maximum values of concentration under different conditions, respectively at 10-13nm and 23-41nm. The range analysis results of the orthogonal experiment show that the slip angle has the greatest influence on the tire wear particle emission, then the speed and the load, the last one is camber angle. Among them, the slip angle has a good exponential relationship with standardized PM10 concentration with base e ($R^2>0.999$).

4. Wear Particles Transportation and Environmental Fate
ETRMA authorized Cardno ChemRisk in United States and Deltares in Netherlands to carry out a research on the transportation path of tire and road wear particles in the environment in March 2017 [9], figure 10. There are three conclusions as follows. (1) TRWP are on average bigger than fine dust with a higher density than water. Diameter and density are the most important parameters affecting the transportation of the TRWP and their possible path to the marine environment. (2) TRWP sink to soil and freshwater sediments. The trapping efficiency of TRWP in freshwater sediments is in the range of 90% and this is supported by the comparison with the average concentration of TRWP measured in the Seine sediments. (3) Actual presence of TRWP in the marine waters has never been demonstrated. Cardno ChemRisk and Deltares modeling calculate a contribution of TRWP to microplastics in estuary in the range of 2-5% (most realistic estimate).
Figure 10. Cardno ChemRisk reports: Task 1 literature review.

Panko [16] has carried out a global sampling research project to measure TRWP concentration in 81 atmosphere samples that come from urban and rural areas in United States, France and Japan. The rubber polymer chemical labeling method based on pyrolysis technology was used to study and analyze the atmosphere samples. Results indicated that TRWP concentrations in the PM10 fraction were low with averages ranging from 0.05 to 0.70 g/m³, representing an average PM10 contribution of 0.84%. At the same time, the This study provides a robust dataset to understand potential human exposures to airborne TRWP.

Unice of Cardno ChemRisk [17] carried out quantitative measurements of TRWP concentration based on GC/MS. The samples came from the sediment of France, Japan and United States. Sampling was carried out in catchments with diverse populations and land, with the result that TRWP was detected in 97% of the samples. The average concentration of TRWP in the sediments ranged from 0.77 to 4.5mg/g. The exposure of freshwater organisms (7 species analyzed) to TRWP in sediments was up to 10 mg/g, but no adverse effects (acute and chronic) were shown. Figure 11 shows the concentration distribution of TRWP in Washington, USA.

Figure 11. The TRWP Concentration of Washington.

5. Trend of Research
Based on the progress of UN WP29 GRPE PMP working group, this article comprehensively expounds the research status of particulate matter emission from tire wear. At present, the international research in this field is in the trial and analysis stage, and there is no systematic, mature and scientific research results system. Therefore, the following prospective directions are proposed to provide references for further research.

(1) Theoretical research on unknown fields: data of road surface, soil and river area, chemical degradation of TRWP, influence of different road surfaces, influence of road drainage system, treatment of microplastics in waste wastes and sewage.
(2) To study the quantifiable test method of TRWP and the method of distinguishing TRWP in mixed particle samples, such as establishing a simulated environment space and conducting a comparative study between simulated space and actual conditions.
(3) Based on the research achievements in China and other countries (Cardno ChemRisk and Deltares, etc.), continue to do in-depth research and expand the application scope of theoretical model.
(4) In order to obtain sufficient basic data to do verification and analysis, it is necessary to carry out long-term monitoring and analysis of TRWP related data in typical areas.

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