Interim Report of Tire Wear Particle Research

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Prepared by:
ChemRisk, Inc. - Pittsburgh, PA; San Francisco, CA, USA

INTRODUCTION

The Tire Industry Project Group (TIPG), working through the World Business Council on Sustainable Development, has embarked on a multi-year research program to understand the potential environmental, health, and ecological impacts associated with tire wear particles. The participating companies include: Bridgestone Corporation, Continental AG, Cooper Tire & Rubber Company, The Goodyear Tire & Rubber Company, Hankook Tire Company, Kumho Tire Company, Inc., Group Michelin, Pirelli Tyre SpA., Sumitomo Rubber Industries, Ltd., Toyo Tire & Rubber Company Ltd., and Yokohama Rubber Co., Ltd.

During 2006, the TIPG reviewed the relevant information and identified data gaps and data needs that would need to be addressed before a robust risk assessment of tire wear particles could be performed. These included:

- Precise definition of tire wear particles
- Physical/chemical data from actual tire wear particles
- Environmentally and biologically relevant studies of actual tire wear particles
- Aquatic toxicity of tire wear particles
- Human exposure to tire wear particles in the environment

This interim report summarizes the research conducted during 2007 and 2008 to address these data gaps.

1.0 WHAT ARE TIRE WEAR PARTICLES?

Tire wear particles (TWP) are released from the tire tread as a result of the interaction between the tire and the pavement.

There are three types of particles that should be defined and distinguished:

- Roadway Particles (RP)
    - Particles on roads composed of a mixture of elements from tires, pavements, fuels, brakes, environmental 'dust', and the atmosphere
- Tire Wear Particles (TWP)
    - Particles produced by the interaction between tires and pavement
- Tire Particles (TP)
    - Particles of pure tire tread rubber, e.g. cryogenic (frozen) grinding

The differences between TWP and other materials present in road dust are shown in Figure 1.

TWP are released directly to the environment onto the road surface and via suspension into the air. Subsequently, the particles can be transported to soil and surface water via roadway run-off and air deposition. Therefore, one objective of the TIPG is to identify the contribution of tires in the generation of RP and assess the potential environmental and health impacts of this contribution.

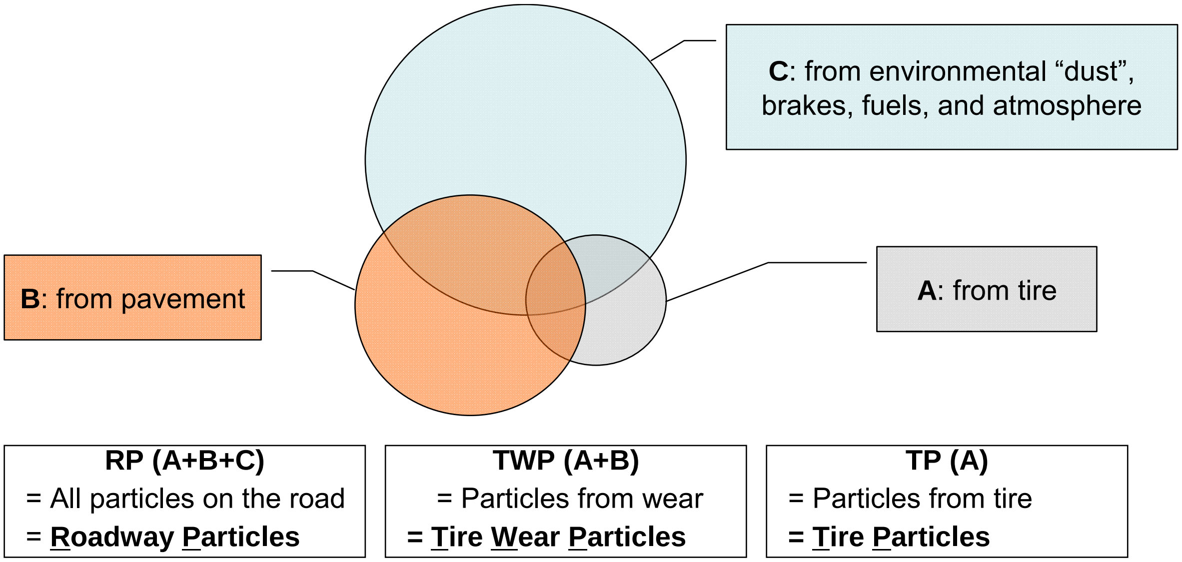

Figure 1. Types of particles that make up road dust

2.0 METHODS FOR COLLECTING TWP

Many experiments have been conducted with materials that were referred to as “TWP”, but the test materials were not TWP but, rather, TP obtained by shavings of tire tread or shredding of whole tires; neither of which is characteristic of the complex TWP formed during tire wear.

Therefore, in this study various methods for collecting TWP under actual driving conditions were examined. The primary goals of the collection effort included: 1) collection of TWP from both cars and trucks, 2) minimization of collection of other road materials and debris, and 3) collection of both the large and small size (respirable) fractions of TWP. With respect to the latter objective, inclusion of small size (respirable) fractions was deemed necessary to fully understand the potential health risks associated with inhalation of TWP.

A collection device was designed by Michelin which attached behind the rear tire of either a passenger car (BMW 528i No. 61 Model year 1999) or truck (Mercedes Actros 1846, 19 Ton). A representative driving circuit was established to account for time spent driving on urban streets and highways and then the vehicles were driven along the circuit to collect particles. Typical tires were used for both the passenger car and the truck. While the particles were collected under real driving conditions from both the car and truck, several technical challenges were associated with the on-road device. Only 20% of the collected particles actually originated from the test tire. The remaining 80% included TWP that had been previously deposited on the road surface by other vehicles, as well as other constituents of road dust. Thus, these particles were considered RP. Additionally, although some $PM_{2.5}$ and PM_{10} particles were captured using the on road system, collect of sufficient quantity of those small particles in isolation from the bulk RP for further testing and analysis was not possible.

To overcome these challenges, two indoor road simulator laboratories that could mimic driving conditions were selected: the Germany Federal Highway Research Institute (BASt) in Bensberg, Germany and the Swedish National Road and Transport Research Institute (VTI) in Linkoping, Sweden. Both BASt and VTI successfully collected TWP without interference from road dust other than pavement. The system at BASt was also programmable to replicate real driving conditions (i.e. acceleration, braking, and steering); the VTI road simulator, however, could only operate at one of three constant speeds. Collection of the small size (respirable) fraction of TWP was straightforward at VTI, but problematic at BASt.

Initial comparisons of the RP collected by the on-road system and the TWP from the laboratories indicated that each were similar in elemental composition and contained a similar amount of rubber. The size distribution of the particles was different. After sieving the particles to less than 150 µm to remove the large stones and other debris, the overall size distribution of the RP was similar to the TWP collected at VTI and somewhat smaller than that of the TWP collected at BAST.

3.0 Physical and Chemical Characterization

The RP and the laboratory generated TWP were subjected to a number of analyses to further characterize physical and chemical traits. Tire tread particles (TP) that were created by crushing frozen tire tread samples were also included in the analysis. While the RP and laboratory generated TWP had a similar elongated cigar-shape when examined microscopically, the TP was bigger and had more jagged edges. The smaller RP and laboratory generated TWP were more spherical than the larger particles. On average, the RP was smaller than the TWP. The mean diameter of the RP was approximately 50 µm. The chemical compositions of the RP, TWP and TP were analyzed and the primary components are shown on Table 1 below.

Table 1. Overall Composition

Primary Components	RP	TWP	TP
Minerals	52%	~60%	15%
Polymers	23%	~40%	46%
Carbon blacks	11%	[a]	19%
Oils/waxes and extractible matters	13%	[a]	19%
Sulfur	1%	[a]	1%

[a] Results of the analyses of the TWP were not available as of the date of this report. However, when results are received, the report will be updated.

Additional analyses of the inorganic and organic components were performed. A variety of different metals were found in both the RP and TP, and except for zinc, the metals concentrations were generally higher in the RP than the TP. This indicates the presences of other on road sources of metals. In the organic fraction of the samples, residues derived from vulcanization accelerators, antioxidants (6PPD, DTPD), and phthalates (DOP, DIOP) were present in minor amounts (i.e., parts per million). Additionally, the RP and TP were analyzed for polycyclic aromatic hydrocarbons (PAH). The PAH content of TP represented only 5% of the total PAH content of the RP, indicating that other on-road sources are more significant contributors to PAHs in RP than tire tread.

4.0 Environmental and Biological Leaching Potential[1]

The next goal of this work was to identify those chemicals and metals that might leach out of the RP under both normal and non-typical environmental conditions. First, the RP and TP were extracted with acetone, an organic solvent, to identify the chemicals contained in the RP and the TP and soluble in this solvent. This solvent extraction is not representative of environmental or biological conditions but rather is a standard test method for the chemical analysis of rubber products (ASTM D-297-93 – 2006). This extraction allowed subsequent analyses to focus on those chemicals that have the potential to leach, instead of analyzing for all of the chemicals found in the tires. The acetone extraction of the RP and TP contained several organic chemicals including oils/wax (stearic acid, palmitic acid, hydrocarbon oils, and wax), antioxidants, and phthalates. Some chemicals used to accelerate vulcanization of the rubber in tires, or their reaction products were detected in the TP (DPG and MBT) but not in the RP.

The RP and TP were next leached in simulated rainwater in accordance with OECD guidelines (OECD, 2004). The rain water was dripped onto columns containing the RP or TP for 16 hours to mimic a significant rainfall event. The water was then collected and tested for organic chemicals and metals. A preliminary test was conducted to identify the pH at which the maximum amount of chemicals or metals would leach. Four different acidity levels were tested and it was found that more metals leached when the water was less acidic. Therefore, all further experiments were conducted using simulated rainwater that was not acidic (pH 7.5). Unlike the harsh conditions created with the organic solvent experiment, no organic chemicals were detected in the water leachate, except formaldehyde. However, the formaldehyde was detected at levels that were too low to be reliably quantified (i.e., <50 ppb). Barium, boron, magnesium, manganese, potassium, silicon, and sodium leached from the RP but did not leach from the TP in significant amounts, suggesting that most of these metals are from road dust and not from the tires. Zinc was detected in the water from both the TP and RP columns. The amount of zinc from the RP columns was about twice as much as was found in the water from the TP columns.

The next goal was to simulate environmental leaching of chemicals from RP that have mixed with soil (as might occur near a roadside). These RP were mixed with soil and placed into glass columns (See Figure 2). Several different concentrations of RP in soil were tested, with the highest concentration set at levels well-above levels of RP that have been ever measured in soil. Again, the soil columns were leached by allowing

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[1] Results of the analyses of the TWP were not available as of the date of this report. However, when results are received, the report will be updated

simulated rainwater to percolate through the columns for 16 hours. The soil leachate water was collected and analyzed for organic chemicals and metals. Similar to the water columns studies, organic chemicals were not present in the leachate. It was noted that although PAHs may be present in RP or TP, no PAHs were detected (<0.5 ppm) in the simulated environmental leachate or in the acetone extractions of RP or TP.

No statistical difference in the amounts of metals was observed in the soil column leachates between soil columns that contained the RP and the experimental controls that contained only soil. However, the column that contained only RP (without soil) leached more magnesium, manganese, potassium, titanium, and zinc than either the soil-only column or any of the RP with soil columns. Therefore, while RP may be a source of soluble zinc, it appears that once the RP become distributed into soils, any zinc that leaches from the RP is bound to the soil. This is consistent with information on the environmental chemistry of zinc which indicates that zinc is unlikely to be leached from soil owing to its adsorption on clay and organic matter[2].

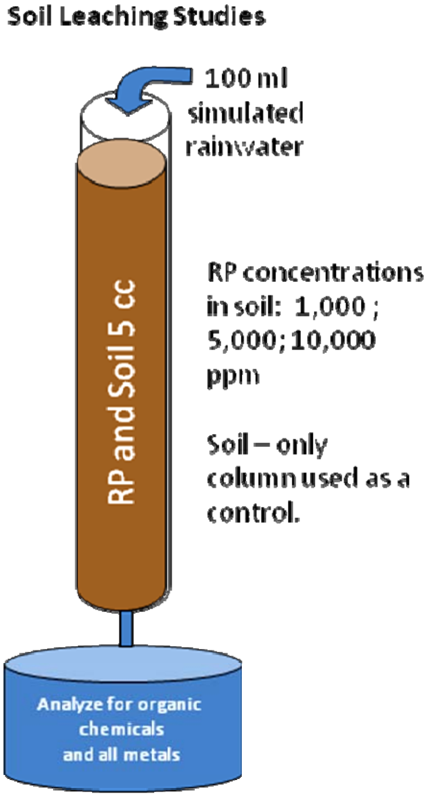

Figure 2. Schematic of soil column set up.

The levels of zinc which leached into water from the RP were also evaluated in a model used to predict the amount of zinc which may enter an ecological habitat near a highway (such as a constructed wetland) after a rainfall event. The modeled zinc levels predicted to be in the wetland were similar to actual levels found in these systems which further

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[2] International Programme on Chemical Safety (2001). Environmental Health Criteria 221 - Zinc. World Health Organization, Geneva, Switzerland.

supports that the levels of zinc found in the leachate in this study are reasonable in terms of understanding the leaching potential of RP in the environment.

5.0 Aquatic Toxicity[3]

The RP was tested for aquatic toxicity in three species according to international standards. The RP was mixed with water and sediment for 24 hours and then the water was allowed to settle and the sediment was removed. The test organisms were placed into the water. The three species tested were green algae, Daphnia (water fleas), and fathead minnows. The green algae were assessed for growth, the Daphnia were assessed for mobility, and the fathead minnows were assessed for survival. These tests were designed to assess acute toxicity of the RP; therefore, all testing was conducted for 24 to 72 hours, depending on the test species. Based on the results of the acute aquatic toxicity testing, the RP was classified as “not acutely toxic” to algae, Daphnia, and fathead minnows.

6.0 Human Exposure

To date, neither RP nor laboratory generated TWP in the airborne size fraction (<10 μm) have been collected, therefore, studies of the potential for biological leaching (i.e., from particles into simulated lung fluids) could not be performed. Activities are currently underway to optimize a sampling system to allow for the collection of small TWP which have the potential to become airborne and possibly inhaled.

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