

Technical Note

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Brake Wear Emissions in Standard Brake Pad Laboratories: A Hidden Occupational Hazard

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Abstract

Brake wear emissions are a major source of non-exhaust particulate matter, yet occupational exposure in brake pad standard laboratories remains significantly underexplored. Workers in these laboratories are exposed to high concentrations of airborne particles, including PM₁₀, PM_{2.5}, ultrafine particles, and toxic metals such as copper, iron, and antimony. These emissions can penetrate deep into the respiratory system, potentially leading to respiratory, cardiovascular, and systemic health issues. Despite growing environmental awareness, the specific risks faced by laboratory personnel are not sufficiently addressed in current occupational health standards. This letter underscores the urgent need for dedicated research and regulatory attention to this overlooked exposure pathway. Effective mitigation strategies such as local exhaust ventilation, high-efficiency filtration, use of personal protective equipment, and safer brake materials should be implemented to reduce health risks. By raising awareness of this issue, we aim to initiate informed discussion among researchers, industry professionals, and policymakers to enhance worker safety in brake wear testing environments.

Keywords Occupational health risks; Non-exhaust particle exposure; brake pad standard laboratory

Introduction

In recent years, the release of particulate matter (PM) caused by the brake wear has been raised as one of the important sources of environmental pollution and health risks for humans [1]. Brake wear emissions are due to the mechanical friction between rotors and brake pads, resulting in generation of a complex mixture of ultrafine particles, heavy metals, and oxides [2]. The characteristics of brake wear emissions, including dimensions, chemical composition, and reactivity, depend on braking conditions, pad and disc materials, temperature, and environmental factors, and are highly variable. Numerous studies have been conducted on exhaust emissions, and there are legislations to regulate them, while according

to the latest studies, non-exhaust particulate matter emissions contribute more significantly to transportation-related pollution [3].

Although studies and legislation related to non-exhaust emissions are gaining attention, insufficient attention has been paid to the risks of occupational exposure to these emissions. Individuals working in standard brake pad laboratories are exposed to significant concentrations of these emissions, raising concerns about their cumulative impact on occupational health. These laboratories are responsible for accurately testing and evaluating brake pads under controlled conditions and simulating real braking scenarios. As a result, workers are routinely exposed to high concentrations of particulate matter, including



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PM10, PM2.5, and ultrafine particles, which can be inhaled and penetrate deep into the respiratory system. Inhaled brake wear particles, especially the fine and ultrafine fractions, can penetrate deep into the lungs, causing irritation, inflammation, and oxidative stress that contribute to respiratory and cardiovascular problems [4]. Additionally, the metallic components (such as iron, copper, and antimony) in these particles can damage lung cells and may disrupt systemic functions, potentially leading to broader health issues [4]. Furthermore, chronic exposure to brake wear emissions may contribute to systemic inflammation and long-term health issues [5].

The composition of brake wear particles varies from that of the constituents used in the brake pads, braking conditions, and test conditions. Most brake pads contain heavy metals such as copper, iron, zinc, and antimony which are toxic if inhaled in high concentrations [6]. Additionally, the heat generated through braking can also lead to the production of reactive oxygen species (ROS) and other harmful substances [1, 7].

Research to date has largely focused on the environmental effects of brake wear particles and their role in urban air pollution. This study aims to address the gap in knowledge regarding brake wear emissions and health of brake pad standard laboratory personnel.

Given the high exposure levels faced by brake standard laboratory personnel, recognizing the occupational hazards of brake wear emissions is critical to ensuring workplace safety. This letter underscores the necessity for targeted research, regulatory oversight, and practical safeguards to protect workers from harmful particulate exposure. By drawing attention to this overlooked dimension of non-exhaust emissions, we aim to prompt meaningful engagement and concrete measures from both policymakers and the scientific community.

2. Composition of Brake Wear Emissions

Brake wear emissions primarily originate from the frictional interaction between brake pads and rotors, generating a complex mixture of airborne particles with diverse physicochemical properties. Modern brake systems commonly use disc configurations with pads composed of multiple components: binders, fibers, fillers, lubricants, and abrasives [1]. These materials vary based on pad types such as non-asbestos organic (NAO), low-metallic, and semi-metallic, which incorporate elements like copper, iron, titanium, antimony, and barium, many of which are toxic or potentially harmful [1, 8].

Particles generated during braking vary in size and composition depending on braking frequency, pressure, material type, and thermal conditions. While larger particles (PM10) dominate the mass distribution, significant frac-

tions fall within the fine (PM2.5) and ultrafine ($<0.1 \mu\text{m}$) ranges. Notably, up to 50% of brake wear particles are smaller than $20 \mu\text{m}$, with PM10 representing around 40% of airborne mass, and ultrafine particles constituting up to 33% by mass in some studies [1, 8]. These fine and ultrafine particles are particularly concerning due to their ability to penetrate deep into the human respiratory system. Chemical analyses of brake wear emissions have consistently identified metal oxides (e.g., Fe, Cu, Zn, Sb), with copper playing a crucial but controversial role due to its thermal conductivity and tribological benefits versus its environmental toxicity [8, 9]. The third body layer—a nanocrystalline interface formed during friction—further complicates composition, consisting mainly of iron oxides that evolve under high temperatures and dynamic contact conditions [1].

Altogether, brake wear emissions form a polydisperse aerosol comprising a broad spectrum of particle sizes and compositions. These particles pose increasing environmental and health risks as exhaust emissions decline and non-exhaust sources like brake wear become more prominent [1, 8].

3. Impacts of Brake Wear Emissions on human health

Brake wear particles pose significant health risks due to their physical size and toxic chemical composition. These emissions contribute up to 55% of non-exhaust traffic-related PM10 in urban environments, often exceeding contributions from tailpipe sources, especially as exhaust emissions decline with regulatory advances [1].

The health hazards stem primarily from the small size of emitted particles, which allow them to penetrate deep into the lungs and even enter systemic circulation. Up to 63% of brake wear particles fall within the PM2.5 fraction, and 33% are ultrafine ($<0.1 \mu\text{m}$), which are especially concerning for their ability to cross the alveolar-capillary barrier and reach other organs [1, 7]. Once in the body, these particles can trigger oxidative stress, inflammation, and DNA damage, particularly due to their high surface area and chemical reactivity.

Brake particles are rich in toxic metals like iron, copper, manganese, chromium, and zinc, which can generate reactive oxygen species and compromise lung cell integrity [7]. Iron-rich particles are particularly harmful when inhaled, bypassing natural iron detox pathways and contributing to respiratory and cardiovascular diseases. Brake wear particles are known to trigger inflammatory responses in lung tissue, contributing to respiratory stress and immune system activation.

Moreover, compounds like antimony trisulfide (Sb_2S_3), used as a lubricant in brake pads, may oxidize to carcinogenic antimony trioxide (Sb_2O_3) during braking, adding

to the toxic burden [4]. Polycyclic aromatic hydrocarbons (PAHs) are released during braking due to thermal degradation of organic resins in brake pads and have been associated with reduced lung cell viability and inflammation [7].

Table 1. Pollutants and their exposure limits

Pollutant	Typical Workplace Concentration	OSHA PEL (US)	HSE WEL (UK)	Ontario OEL (Canada)
PM2.5	35 µg/m ³ (urban industrial average)	No specific PEL	No specific WEL	No specific OEL
Copper (fume)	0.05-0.1 mg/m ³ (welding, smelting)	0.1 mg/m ³	0.2 mg/m ³	0.2 mg/m ³
Copper (dust/mist)	0.5-1 mg/m ³ (machining, grinding)	1 mg/m ³	1 mg/m ³	1 mg/m ³
Antimony	0.1-0.5 mg/m ³ (battery, alloy work)	0.5 mg/m ³	0.5 mg/m ³ HSE	0.5 mg/m ³ Ontario.ca
Iron oxide (fume)	1-5 mg/m ³ (welding, foundry)	10 mg/m ³	5 mg/m ³	5 mg/m ³

In summary, brake wear emissions present a multifaceted threat to human health due to their ultrafine size, metal content, and chemical toxicity, necessitating greater regulatory attention.

4. Occupational Exposure in Brake Standard Laboratories

Brake standard laboratories, where braking systems are rigorously tested, present a significant risk of occupational exposure to brake wear emissions. Technicians and engineers working in these facilities may be routinely ex-

posed to airborne particulate matter (PM), including fine (PM2.5) and ultrafine particles, along with heavy metals such as copper, iron, and antimony released during the wear process. Without proper ventilation and protective measures, these particles can accumulate in the workspace, increasing the risk of inhalation. Prolonged exposure can lead to respiratory issues, cardiovascular stress, and systemic inflammation. Workers may also be exposed to organic compounds, including phenols and polycyclic aromatic hydrocarbons, which may pose carcinogenic risks. The confined nature of laboratories can exacerbate concentration levels, making exposure assessments and safety regulations essential. Occupational health guidelines recommend continuous air monitoring, personal protective equipment (PPE), and engineered controls such as high-efficiency particulate air (HEPA) filtration systems to minimize health risks.

5. Exposure Mitigation Strategies

Reducing exposure to brake wear emissions requires a combination of engineering, administrative, and personal protective (PPE) strategies. In laboratory and industrial environments, installing local exhaust ventilation (LEV) systems equipped with HEPA filters is critical for capturing fine and ultrafine particles at their source. Regular air quality monitoring ensures these systems remain efficient. PPE, such as N95 or P100 respirators, gloves, and coveralls, should be mandatory in high-exposure zones. Administrative measures, including limiting exposure durations, rotating personnel, and conducting regular health screenings, help manage long-term risks. Furthermore, transitioning to low-emission or copper-free brake materials can significantly reduce the generation of toxic particles. On a broader scale, encouraging the adoption of regenerative braking systems in electric and hybrid vehicles presents a promising pathway to minimize wear-related emissions, offering both occupational and environmental health benefits.

6. Conclusion

Brake wear emissions represent an often underappreciated yet significant contributor to both environmental pollution and human health risks. This paper has underscored the complex composition of brake wear particles, highlighting their variable sizes—from coarse to ultrafine—and their potentially hazardous constituents, including heavy metals and reactive compounds. The evidence presented confirms that these emissions not only contribute substantially to urban PM pollution but also expose laboratory workers in brake standard facilities to elevated concentrations of toxic particles. Such exposure poses serious respiratory, cardiovascular, and systemic health

threats, exacerbating concerns over occupational safety. Moreover, the discussion on exposure mitigation strategies, ranging from advanced engineering controls such as local exhaust ventilation and HEPA filters to administrative measures and the adoption of low-emission brake materials, emphasizes the urgent need for integrated approaches to protect worker health and reduce environmental impacts. As regulatory focus shifts towards non-exhaust emissions, further research is essential to refine our understanding of exposure thresholds and to develop innovative, sustainable technologies in braking systems. By addressing these challenges, stakeholders can ensure safer work environments and contribute to broader public health improvements.

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Declarations

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Not applicable.

Consent for publication

Not applicable.

Competing interests

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