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Tyre-Induced Microplastics: An Unknown Arena for e-Mobility

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ABSTRACT

Non-exhaust emissions constitute vehicular emissions released from brakes, tyres, and road dust resuspension. Brake emissions are quantified using particulate matter (PM), and tyre emissions primarily represent the traffic-related microplastics. Road dust is an agglomerate of emissions released from traffic and non-traffic sources. Tyre abrasion has gained traction in the last two decades, owing to the large presence of tyre and road wear tracers in the microplastics sedimented in the soil or runoff to oceans (reaching 50% or above in several countries). The sampling methods or mitigation measures are at an early stage for both brakes and tyres. Research on brake emissions, however, is more concrete, and the test method will be standardized with the upcoming Euro 7 regulation limits set for PM₁₀ (particles less than 10 µm). Tyre abrasion depends on several factors external to the tyre design such as driving behavior, weather conditions, and vehicle mass. With the global uptake of electric vehicle (EV) adoption, it is important to investigate the existing widespread approach that the increased EV weight is the single determining factor to estimate the tyre-induced microplastics. This article, according to our research, provides a novel assessment on different influencing factors specific to EV applications that should be considered when determining the tyre-induced wear for an EV.

Keywords: Tyre-induced microplastics, Non-exhaust emissions, Electric vehicle weight, Tyre abrasion, Lightweighting techniques

Introduction

The word ‘plastic’ is derived from the Greek word ‘plastikos’, meaning that it is capable of being shaped or molded. This very feature of plastics is what makes it a major source for us to use it as we please. Single-use plastics i.e., use once and throw away, became an integral part of human lives. They are the best options for keeping our hands, bags, and car interiors clean, as they are disposed of after consuming food and beverages during a trip. They are also the instant virtual housekeepers who clean up the house after a party by volunteering to fall into a bin or in another large plastic bag. According to a recent report, about one million plastic bottles are purchased every minute, and it is not uncommon to treat these bottles for single-use purpose.¹ On the other side of the story, less than 10% of the plastic waste is recycled. So, the fate of the remaining 90% plastic waste is something that requires prompt attention from every user of plastic, which is almost everyone on the globe. This explains the motive behind various initiatives focused on ‘reduce, reuse, and recycle’ policies created to control plastic waste.

Plastic is a malleable material consisting of synthetic and semi-synthetic organic compounds or polymers. Microplastics, which have a particle size of 5 mm or less, are majorly categorized as primary and secondary types. The primary microplastics are produced in the microscopic size and are incorporated as a raw material by the (plastic/cosmetics/textile/rubber) product manufacturer to achieve the desired feature. In the emission context, primary microplastics are directly released into the environment. Secondary microplastics are the degradation or debris that arise because of wear and tear of the original end-user products. These microplastics are deposited in the soil, airborne, or mobilized via runoff and wind into water bodies such as rivers and oceans, thereby intruding the aquatic life. Plastic pollution of the marine ecosystem is the source of immediate measures identified to control microplastics. Land-based sources and rivers carry 70–80% of plastics, thereby dumping into the oceans.² Therefore, it becomes imperative to understand the effect of microplastics on the aquatic ecosystem.

Microplastics are small enough to be ingested by planktonic organisms. Ingestion of microplastics can block the digestive tract, hinder growth, and affect hormones and the reproduction system.³ Aquatic organisms include amphipods, copepods, lugworms, barnacles, mussels, decapod crustaceans, seabirds, fish, and turtles.⁴ Differences in shape (e.g., spheres, fiber, film, and irregular) and density (from 16 to 2200 kg m⁻³) cause microplastics to interact with different organisms.⁵ According to a 2016 report, microplastic contamination might have been higher in the San Francisco Bay area compared to other urban water bodies in North America.⁶ In a subsequent news article, California became the first government in the world to mandate testing drinking water, owing to the presence of microplastics in water bodies.⁷ Also, measures are being proposed by various researchers to remove microplastics from aquatic environments using biodegradable sponge materials, Mg/Zn magnetic biochar, micro-/nanomotors, hydrophobic catalysts, filtration systems, and other natural methods.⁸ Some of these methods are temporary solutions and can become complex as we switch from urban estuaries to larger water bodies and marine ecosystem. Therefore, there is an immediate need to mitigate and control sources of microplastics. As part of its goal towards zero pollution for air, water, and soil, the EU mandates a 30% reduction in microplastics by 2030.⁹ Tyre (or ‘Tire’) wear contributes to the majority of microplastic emissions.^{10,11} Henceforth, understanding the status of tyre-induced wear provides a direct implication of microplastics in the environment. In this context, it is important to note

that the tyre-induced wear can be a combination of tyre wear particles (TWP) as well as road wear particles. This combination of tyre and road wear is referred to as the TRWP emissions in the literature.

The formation, properties, and evolution of TRWP have been reviewed by various researchers from inter-disciplinary fields including environmental & life sciences, engineering, and organic chemistry.^{12–14} There remains, however, a significant gap in the practical knowledge of measurements made on TRWPs in an experimental setting. Most of the articles continue to rely on emission factor models which are older by around a decade or more.¹⁵ A recent article by several ‘backend developers’ of Euro 7 regulation provides a comprehensive overview of measured data on tyre abrasion using approximately 300 data points.¹⁶ According to their analysis, a mean abrasion of 110 mg/km was derived for passenger cars. The rate of TRWP is in general attributed to the driving behavior, vehicle configuration, road surface, and weather conditions, apart from the tyre design.¹⁷ Among these factors, driving style, road surface & topology, and the vehicle configuration carry higher weightage in influencing the TRWP emissions.¹⁸ Vehicle configuration can represent the effects of powertrain, vehicle mass, drive axle type (FWD/RWD/AWD), suspension, and steering system.

According to a 2023 report by the International Energy Agency, electric vehicle (EV) sales account for 18% of global car sales with larger vehicles (medium-large cars, SUVs, pickup trucks), contributing two-thirds of the EV stock.¹⁹ EVs in this context included both battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs), with the former occupying a larger stock than the latter. Notably, BEVs are projected to be heavier than an equivalent internal combustion engine vehicle (ICEV) due to the increased mass of the battery. According to previous findings, this difference between BEVs and the equivalent ICEV for larger vehicles such as SUV can be up to 25%.^{20,21} There are some prominent studies made on comparisons of non-exhaust emissions between BEV and ICEV. Beddows and Harrison conducted a data analysis of various vehicle types using emission factors taken from the EMEP/EEA emission inventory guidebook.²⁰ A regression analysis with vehicle mass as the independent variable showed that the estimated emission factors for BEV (increased mass) in PM10 metric are 7–12% more than for an equivalent ICEV. While the study included the emission factor estimates for brakes, tyres, and resuspension, the results and inferences were more focused on brakes and how regenerative braking can nullify the increased mass of BEVs. In addition, the authors acknowledged that the values presented carry uncertainty by virtue of the variability of values available in the literature, thereby highlighting the importance of having more measurement data.²⁰ Timmer and Achten applied the emission factors taken from the EcoInvent’s database (Switzerland) and estimated that the tyre-wear PM10 for BEV is 18% more than for an equivalent ICEV.^{21,22} All these studies, along with their

included results, exhibit at least one of the following limitations or underlying assumptions:

1. There are minimal, if not zero, samples of battery-powered vehicles in these inventories at the time. These databases might be highly skewed with emission values taken from only vehicle models equipped with fossil fuel powertrains (petrol, diesel, and natural gas) and making subsequent projections for BEVs.
2. Electric vehicle(s) for an ‘equivalent engine power output’ may undergo certain changes in the vehicle design features which these studies did not consider while estimating the tyre-induced emissions. To begin with, BEVs can be fitted with special tyres designed to meet certain requirements.
 - a. Dimensional redesign to roll more weight with less resistance.
 - b. Noise compliance as the road noise is magnified after removal of the engine noise factor from the BEV.
 - c. Tyre tread and shaping to tolerate the strain caused by the instant acceleration that the e-motor can provide, unlike an ICE.
3. Electric vehicles can be incorporated with lightweight materials and optimized production methods to compensate for the heavier batteries.

Therefore, it is both crucial and technically precise to understand tyre-induced emissions or microplastics from EVs by including actual BEV test results in the inventory models. An OECD 2020 report stated a weight difference of only 4%–6% for lighter BEV (100-mile range) and 34%–41% for heavier BEV (300-mile range), compared to ICEV weight in their vehicle classes.²³ Non-exhaust emissions (PM2.5 & PM10) from the lighter BEV were analyzed to be lower than for ICEV whereas the tyre-induced PM2.5 (viz. microplastics) from the heavier BEV was greater than from the ICEV. These results are different from previous studies in a few respects. BEVs can be heavier than ICEV by more than the conventional value of 25% used in the empirical models. Even with such a high difference of 41% in vehicle weight, the tyre PM2.5 from the corresponding BEV increased by only 8% maximum compared to the equivalent ICEV. Unlike the existing literature that treats BEV as an ICEV with a ‘ballast’ weight added to it, the current article reviews a range of factors that can potentially influence the tyre-induced microplastics released from BEVs. As shown in Figure 1, the fate of tyre-induced microplastics can be determined only after addressing several vehicle and tyre-related factors, some of which can also change the net weight of the BEV.

These factors are covered in the following sections as follows. Section II highlights several lightweighting techniques potentially applicable to EVs using advanced production methods or material selection. Section III provides an overview of the critical differences that are directly applicable to the EV tyre design, compared to a conventional tyre. Section IV presents a

novel method being developed for tyre abrasion measurements. In addition, several recommendations are included from the author’s perspective on activities related to tyre manufacturers, raw material suppliers, and dealers. Section V includes concluding remarks.

Electric Vehicle – Platform

Car makers usually employ two approaches to introduce a new electric vehicle in the market – Upgrading an existing (conventional) vehicle platform and vehicle model or add a new platform.²⁴ Car makers who have a high reputation in the ICEV market might select a mixed assembly line (making EVs and ICEVs alternatively). Such a platform-sharing business model comes with several advantages – reduced upgrade costs of existing plants, established process workflows, just-in-time practices, and optimized layouts. For example, Hyundai Kona seems to share the same vehicle body for three powertrain configurations: gasoline, diesel, and BEV (25). When comparing these powertrain configurations of Hyundai Kona, the tyre tread wear rate of

the BEV version was 1.2 times more than the ICEV.²⁵ In another study, the BMW X1 and BMW iX1 were mentioned to share the same model platform wherein the base model (engine) itself includes reduced chassis weight.^{26,27} The results indicated a similarity of the total tyre-wheel assembly weight loss for both ICEV and BEV when normalized with the vehicle weight.²⁷ To offset the additional battery weight, some car makers deploy novel casting methods as well as light-weighting technologies to produce EV models. This requires the design of a new platform. Unlike an ICEV, an EV platform resembles a skateboard, as depicted in Figures 1 and 2. The battery pack would be mounted at the center in a horizontal stacking arrangement. This leads to a uniform weight distribution when compared to the eccentric mass induced by the engine mounted on one side of the vehicle (front side for passenger cars). The electric motors may contribute some mass imbalance on the BEV between the front and rear axle depending on the sizes. Nevertheless, because the battery mass (heaviest component of BEV²⁸) is evenly distributed, the BEVs have a huge leverage over ICEV regarding the ride handling and safety characteristics with its low center of gravity design. Such a flat ‘skateboard’ platform may also benefit from mega casting techniques. In mega casting or giga casting or hyper casting, single-large (aluminum or high-strength steel) metal pieces are cast without needing additional cutting, shaping, finishing, and parts subassemblies.²⁹ By avoiding subassembly of multiple smaller components, car makers can achieve significant weight savings with an enhancing structural rigidity and crashworthiness. Mega casting is implemented by various EV car makers.³⁰ Tesla pioneered the installation of a large aluminum casting for the rear section of the Model Y’s body structure, which is a replacement of around 70 stampings, extrusions, and castings used in Model 3.³¹

Another way to tackle the vehicle’s additional weight due to batteries is the lightweighting approach. For instance, the lightweighting application of body-in-white can lead to downsized battery pack and

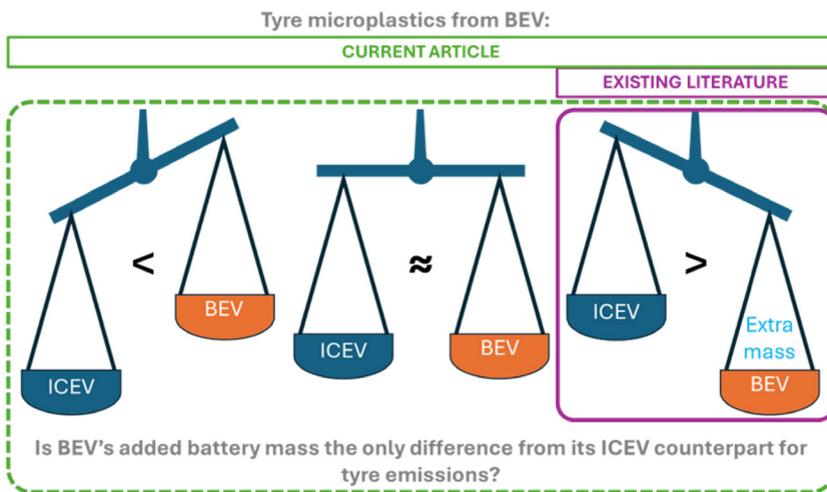


Fig 1 | Knowledge gap exists on tyre wear emission factors for BEVs and ICEVs

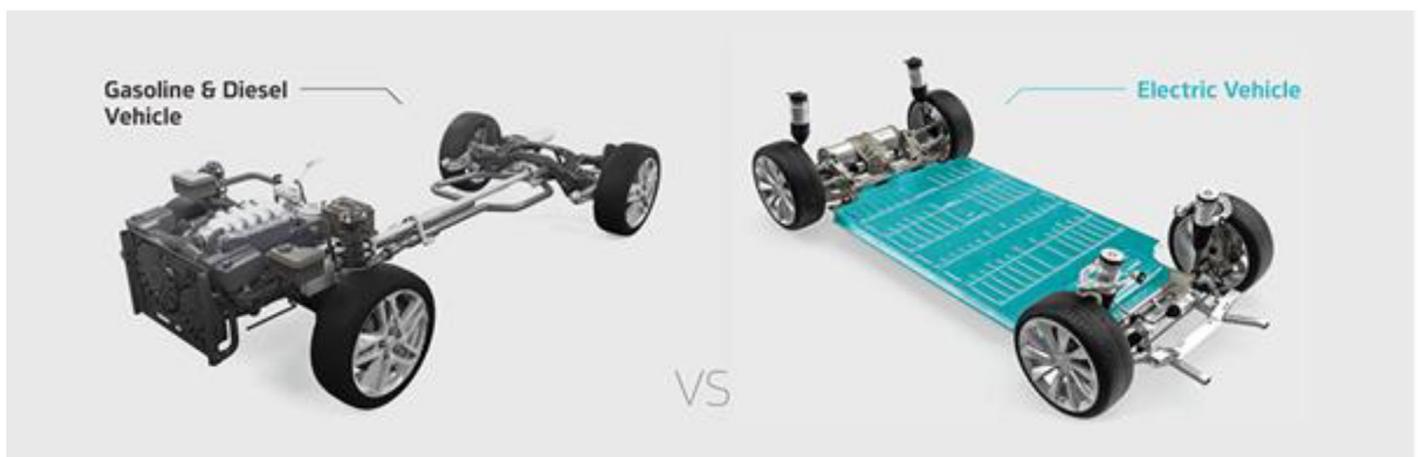


Fig 2 | Platform comparisons: (left) ICEV with the engine assembly located on the front; (right) BEV with the battery load uniformly distributed at the center

Source: Hankook and Company⁶⁸

suspension systems.³² Materials selection such as high-strength steels (HSS), magnesium, aluminum, and reinforced plastics are paving their way into EV lightweighting technology.³³ Magnesium when mixed with aluminum or other metals carries a high power-to-weight ratio value which favors its potential usage in EV components.^{34,35} Table 1 lists the scope of lightweight materials in reducing the vehicle mass as published by the Department of Energy.³⁶ The percentages listed here indicate that by switching from steel to any other lightweight materials can bring down the overall weight of the car by at least 25% which is the nominal percent weight of a BEV battery.³⁷ Also, this value matches with the additional weight assumed by the legacy emission models for BEVs.¹⁵ Apart from offering weight reduction, the chosen material should also be compatible with the manufacturing landscape, strength requirements, and sustainability. The HSS may be an economical choice for battery cover designs due to its high manufacturability when compared to aluminum whereas composite materials offer largest weight savings.³⁸ The cost of battery shell made with a patented cold-rolled martensitic ultra HSS is only half of that made with aluminum.³⁹ Also, HSS is tagged with minimal carbon footprint apart from high mechanical resistance.⁴⁰ In contrast, aluminum can be a better and productive choice for chassis, floor pan, and body panel.⁴¹ Zhang and Xu discussed the merits and challenges of various lightweight materials.⁴² A common drawback for all lightweight materials is the high cost of raw materials and processing costs compared to those for conventional steels. Nevertheless, the cost savings attained with the downsized battery and motor are expected to overcome this additional material cost. Magnesium and synthetic composites share the challenge of undeveloped manufacturing technologies for mass production. Multi-material designs are a viable solution for the immediate EV manufacturing needs. A major challenge in selecting multi-material designs is the ability to join dissimilar metals. For instance, weldment of aluminum alloys and HSS is difficult due to differences in thermal and electrical conductivity and melting points.⁴³ In addition, joining polymer-based fiber composites and metals is challenging because of internal thermal stresses. Nevertheless, multi-material designs showed great success in several commercial applications. Tesla Model S is a proven

BEV that uses 190 kg of aluminum in its body and chassis.⁴⁴ Also, Tesla's giga casting of rear under-body parts are made of aluminum. The 2015 Ford F150 pickup truck with a 5-star safety rating embraced the extensive usage of aluminum body and advanced HSS frame, thereby shedding about 700 pounds (about 315 kg) of conventional vehicle weight.⁴⁵ In both cases, the main motive behind the lightweight was to curb greenhouse gas emissions and improve fuel efficiency or driving range by reducing vehicle weight by 10%. Other innovative choices in lightweighting different components can also contribute to weight reduction, increased range, and reduced tyre-induced microplastics. At the Consumers Electronics Show in Las Vegas, Panasonic and Honda showcased different innovative items, both targeting lightweighting.⁴⁶ Panasonic showcased the downsized speaker and audio systems in the Fisker's Ocean One e-SUV and claims a weight reduction of up to 40% compared to the conventional audio system. At the same show, Honda revealed their progress update on the solid-state EV battery which will significantly reduce the existing weight of batteries made with lithium-ion composition.

In a hypothetical scenario, a car maker using advanced design and manufacturing techniques for an EV model may bring down the weight difference between the BEV and its ICEV counterpart. This weight reduction would subsequently reduce the tyre-induced microplastics from EV compared to existing studies. A counter argument to this hypothesis can be that such lightweighting concepts can be applicable to ICEVs as well which would again create an imbalance in EV's heavy weight. While this can be true in some cases, the lightweighting materials identified for EVs carry additional requirements such as shock resistance and high thermal conductivity to withstand the enclosed EV battery and e-motor operation.⁴⁷ Therefore, the tyre-induced microplastics per vehicle (mg/km or mg/km/t) for a BEV can be determined only with actual vehicles or with certain calibration factors or weightage ratings applied to the empirical models.

Electric Vehicle – Tyre

Another potential discrepancy that can skew the projections of tyre-induced microplastics using legacy emission factors is the tyre itself. Vehicle tyre predominantly consists of rubber (natural & synthetic), followed by reinforced fillers (e.g., carbon black and silica), steel belts, additives, and textile overlays.^{48,49} Natural rubber provides the tear and fatigue crack resistance to tyres. Two synthetic rubber polymers (butadiene and styrene butadiene rubber) define the tyre operating characteristics such as the rolling resistance and traction. Fillers (carbon black or silica) control the tyre deformation and can also improve heat dissipation. These are used to improve the tyre abrasion as natural rubber by itself cannot withstand the abrasive forces experienced for prolonged durations during normal driving. Carbon black in tyres enhances various properties such as reinforcing rubber, UV protection, increase traction, and improve abrasion

Table 1 | Potential reduction in vehicle mass using various lightweight materials³⁶

Lightweight Material	Mass Reduction
Magnesium	30–70%
Carbon fiber composites	50–70%
Aluminum and Al matrix composites	30–60%
Titanium	40–55%
Glass fiber composites	25–35%
Advanced high strength steel	15–25%
High strength steel	10–28%

resistance.⁵⁰ Tyre composition changes by season (summer & winter).⁵¹ Winter tyres consist of a higher percent natural rubber and a deep tread pattern. These are made softer to increase the contact area with the road surface and enhance grip on wet-slippery roads. In contrast, summer tyres are made of less natural rubber content, and this rigid structure provides a low friction coefficient.⁵² Due to their softer nature along with higher natural rubber content, winter tyres tend to wear more, sometimes up to 3x more than the summer tyres.^{53,54}

Tyre manufacturers diligently follow certain design principles for EV tyres. The long-term intent of all manufacturers is to have tyres designed agnostic to the vehicle type. The driving force for such efforts, however, starts from satisfying the EV requirements as acknowledged by various tyre manufacturers, as listed in Table 2.⁵⁵⁻⁶² The key design targets for these EV-ready tyres are to reduce the rolling resistance (RR), tyre-road interaction noise reduction (NR), and enhance the tyre grip. Tyre manufacturers apply proprietary compositional changes to achieve these targets. While these are kept confidential, certain design parameters are also fine-tuned for EV applications. Low RR can be achieved by re-defining the tread depth, pattern, and the aerodynamic shape of the tyre (controlled flow wake behind the tyre).⁶³ In-cabin noise is a common complaint by customers while driving on the roads. In-cabin noise sources can include factors such as the air conditioning system, engine, brakes, wind, or the tyre-road interactions.⁶⁴⁻⁶⁷ Among these sources, the tyre-road interaction noise is predominant in EVs where the conventional (loud) acoustic signature of the engines is absent. Inside an EV cabin, the tyre-road noise can be about 40% and wind noise is estimated to be 30%.⁶⁸ With almost half of the noise levels coming from

tyre-road interactions, all tyre manufacturers are working towards bringing this noise down to near-zero levels to address the EV user concerns. Some of the noise reduction techniques shared by the tyre manufacturers are foam inserts, cavity shapes, acoustic absorbers, tread pitch patterns, and rubber composition. BEVs with their centrally located batteries provide better traction control. However, the instant peak torques from the e-motors require EV tyres to sustain the additional strain experienced during acceleration. Similarly, high driving torques and heavier vehicles with conventional EV designs lead to longer stopping distances. The consequences of instant acceleration and delayed stopping can be addressed by improving the grip capacity of the tyres. Also, the tyre inflation pressure is set at a higher value compared to those fitted for ICEV.⁶⁹ A combination of both lower RR and enhanced grip can result in increased range and/or reduced wear. The extended mileage using the EV-ready tyres ranges from 5% to 22%.

Outlook

Car makers may invest heavily on vehicle lightweighting with precise selection of multi-materials for the vehicle body parts, chassis, and powertrain components. Car makers may work with material scientists to identify suitable alloy compositions to improve the formability of aluminum and magnesium as these currently pose manufacturing constraints at room conditions. In doing so, car makers can benefit from circular economy perks as aluminum chips, for example, can be recycled with a 95% recovery through hot forging instead of melting, thereby receiving cost savings (reduced raw material orders and low-energy recycling).⁷⁰ Advanced materials can

Tyre Manufacture	Tyre Technology	Tyre Features for EV
Continental ⁵⁵	EcoContact™ 6	<ul style="list-style-type: none"> • Low RR • Grip additives for reduced braking distance Built with NR technology
Bridgestone ⁵⁶	Turanza 6	<ul style="list-style-type: none"> • 22% greater mileage than its predecessors 4% lower RR • Sponge-like absorber for NR
Michelin ⁵⁷	Pilot Sport EV	<ul style="list-style-type: none"> • 15% more cornering stiffness for increased EV mass • 60 km additional battery range • 20% reduced cabin noise perception
Michelin ⁵⁷	e.Primacy	<ul style="list-style-type: none"> • 7% increase in battery range
Apollo ⁵⁸	Amperion	<ul style="list-style-type: none"> • 5% increase in battery range Cavity contour for reduced RR Multi-pitch tread for NR • Higher land area for reduced wear
Pirelli ⁵⁹	ELECT™	<ul style="list-style-type: none"> • Up to 10% increase in battery range • 3.5% increased contact area for enhanced grip 20% reduced noise perception
Nokian Tyres ⁶⁰	Electric Fit™	<ul style="list-style-type: none"> • Size-tailored product. Seamless compatibility to both ICEV and BEV requirements
Ceat ⁶¹	EnergyDrive	<ul style="list-style-type: none"> • Lower groove width for reduced RR • Pitch sequencing for NR
Goodyear ⁶²	ElectricDrive™ 2	<ul style="list-style-type: none"> • Aerodynamic sidewall and compound selection for reduced RR • Foam inserts for NR • Compound selection to improve battery range

also support the legislators' vision towards reduction of TRWPs. The AL-7075 T6 can be a potential advanced grade of aluminum which when selected for car frames cleared the virtual crash tests.⁷¹ At last, advanced grades of steel may be introduced towards any possible volume savings and thus cost savings. For example, the bendability and impact strength of martensitic steel can be improved by changing the structure and incorporating a mixed structure of martensite and retained austenite.³⁹ Such initiatives can be helpful especially for BEVs to stay competent with their ICEV counterparts with reference to vehicle weight and the subsequent TRWPs.

A recent user survey on tyre wear revealed that approximately 36% of the BEV private owners use special tyres on their vehicles, and tyre wear can be similar for both ICE and EV when soft driving style is applied.⁷² This percentage shows a promising penetration of special tyres into the EV market, and thus, the BEVs should be evaluated using such tyres to understand their performance on tyre wear and microplastics. In another news, the Californian government took an initiative on updating their emission factors inventory by including brake particulate emissions.⁷³ The model of emission factors 'EMFAC 2021' was fine-tuned based on two extensive measurement campaigns (around 90 measurements of PM10) completed using ICEV, PHEV, and BEV models. Results showed that the brake particulates PM10 from the BEV model was about 45% of PM10 emitted from the PHEV model and around 5x less than for a ICEV model in its vehicle class.^{74,75} Though the current author does not imply a direct correlation of reduction in EV tyre microplastics from the California studies on brakes, they serve as good examples of the need for campaigns using actual EV samples to assess tyre wear.

Tyre Measurement Method

Tyre microplastics from road samples are reported in normalized mass units (e.g., ug/g) using microscopic detection methods such as the pyrolyzer-gas chromatography/mass spectrometry (py-GC/MS).⁷⁶ Tyre microplastics from a laboratory test setting are reported in normalized distance units (mg/km or mg/km/t) per vehicle using road simulation setups such as the flat bed tyre test facility (VTI Sweden), inner drum, or a chassis dynamometer.⁷⁷ Such a diversified range of measurement methods creates a great challenge in making data feature correlations and finding potential source apportionments for tyre-induced microplastics. To address this issue, the Working Party on Noise and Tyres (Groupe Rapporteur Bruit et Pneumatiques-GRBP) under the auspices of the Vehicle Regulations of the UNECE is working on a proposal for tyre abrasion measurements.⁷⁸ According to the ongoing informal document, there are two methods that the test facility can choose from. The first method is an on-road vehicle test procedure that uses a reference tyre in a convoy arrangement, where like vehicles travel together. Both the reference tyre and the test tyre undergo real-time driving loads. As an alternative, an indoor lab test

procedure can be carried in the second method using a textured drum simulating different road abrasion conditions. The latter method is subdivided into two options, depending on whether the reference and the test tyres complete a predefined cycle simultaneously or one at a time in a predefined sequence. A high-level outline of the working group's proposal to the GRBP can be depicted using Figure 3.

Tyre Makers

Tyre design may also define the release of tyre-induced microplastics. Currently, measured data are unavailable to approve/disapprove the emission levels of the existing EV-ready tyres with reference to ICEV emissions. However, the tyre manufacturers are expected to keep abreast of the forthcoming requirements on microplastics regulations and offer a professional coordination in the development of the tyre emissions test protocol. The latter can be a crucial decision as the tyre operational parameters have a greater influence on rolling resistance (and wear) compared to the tyre design parameters, as claimed by many tyre manufacturers.^{18,79} Deflated tyres would increase the rolling resistance and subsequently release more tyre-induced microplastics. Tyre manufacturers may work in tandem with car makers in developing certain 'emergency-range' features. In this concept feature, when the tyre pressure on the EV drops below the recommended tolerance, the car control unit would place a range restriction such that the EV can reach the nearest air filling station. Upon inflating to the recommended pressure, the remaining range shall be made accessible again for driving. Such self-control policies are highly beneficial for BEVs whose range is very sensitive to properly inflated tyres. Also, the proposed concept is feasible to deploy for autonomous vehicles because all the information on location, vehicle status, and time of the day are available in real time for such vehicles. Nevertheless, this is a concept proposed by the current author and requires prototype trials for the feature validations.

Green Tyres

Carbon black is predominantly used for tyres to increase the elastic-reinforcement properties of the tyre. However, this reinforcing agent is commonly derived from partial burning of the fossil fuel which amongst other factors is an environmental hazard. In favor of the EU's circular economy action plan, the tyre manufacturers can use carbon black that is produced from renewable sources such as spent tyre pyrolysis oil.⁸⁰ Another 100% renewable source for carbon black production is the biomass obtained as a by-product during the crude palm oil production.⁸¹ Oil palm biomass shall, however, be pretreated and prepared before it can be used as a feedstock and fuel for carbon black production. Hydrolysis, carbonization, and pyrolysis of green algae and sugarcane bagasse were recently experimented to prepare carbon black separately from each renewable source.⁸² The morphology of carbon black prepared with both biomass sources

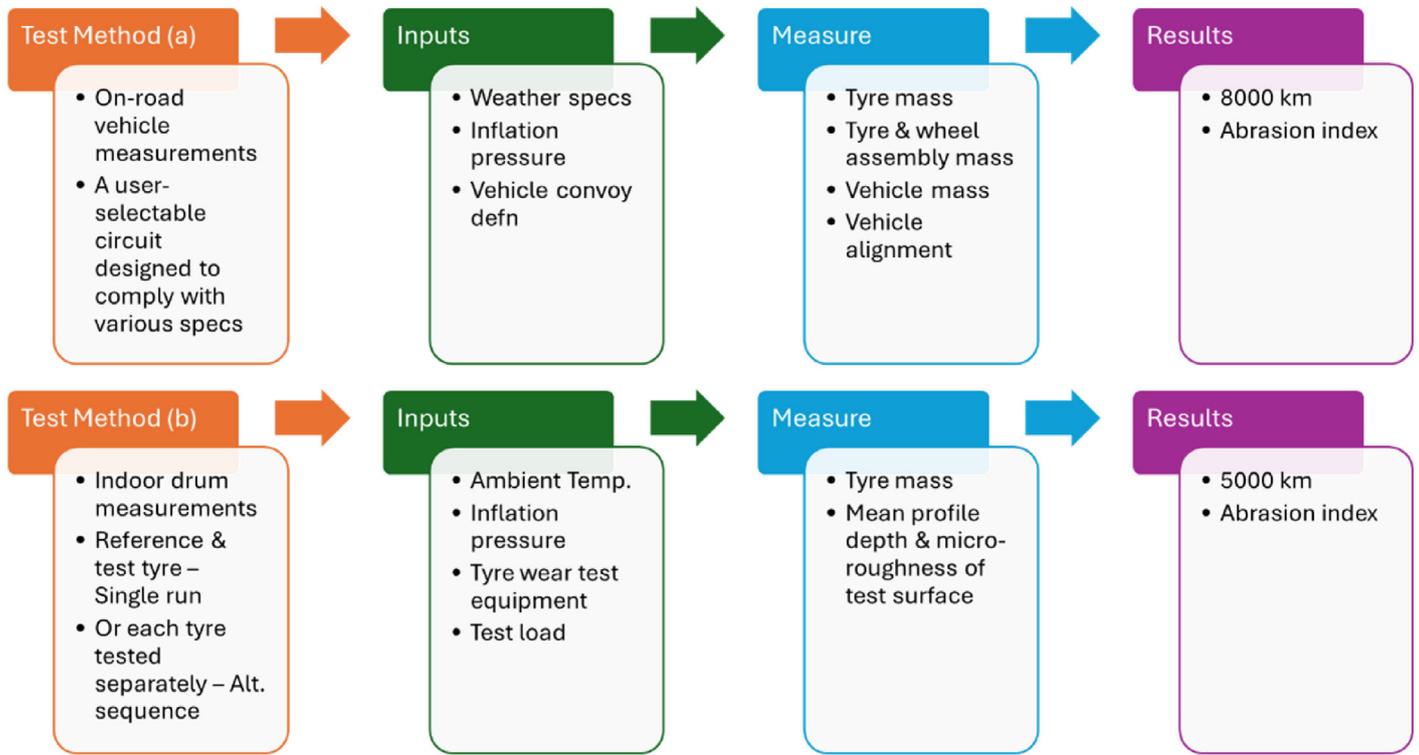


Fig 3 | Proposed methods of the UNECE’s informal working group for measuring tyre abrasion

matched well when compared with a reference commercially available carbon black. The carbon black prepared with sugarcane bagasse had a very high specific surface area. The textural properties confirmed that carbon black created with either biomass sources were rich in micropores whereas the commercially available carbon black made from fossil fuel was rich in meso-scale pores. Several renewable feedstock sources are at an early stage of development, and the feedstock composition decides the (carbon black) formation mechanism.^{83,84} Solid carbon residue recovered from tyre pyrolysis can potentially become a renewable feedstock with a technology readiness of up to 9 (industrialized scale). Few other sources such as methane pyrolysis, wood, or other non-fossils are rated with a technology readiness of only 6 to 7 (pilot production or demonstration stages).

A different strategy in making greener tyres is to identify potential reinforcement alternatives to carbon black. Bijina et al. reviewed various sustainable sources that can significantly reduce the greenhouse gas emissions originated from tyre manufacturing or in-use.⁸⁵ A list of different substitutes or blended alternatives for the existing raw materials in tyre manufacturing are shown in Table 3.^{85,86} Silica seems to be a robust and cleaner replacement when blended with a few compounds to substitute carbon black.

Silica filled with a blend of epoxidized natural rubber and butadiene rubber resulted in superior mechanical properties matching the carbon black performance levels. The epoxidized natural rubber in tyres was found to offer excellent wet grip and lower rolling resistance.⁸⁷ Researchers also identified green

Table 3 | Potential replacements for sustainable policy tyres

Raw Material	Sustainable Choice
Rubber	<ul style="list-style-type: none"> Liquid farnesene rubber (LFR) Sugarcane originated LFR
Carbon black	<ul style="list-style-type: none"> Polar silica Blends of silica and styrene butadiene Blends of silica and poly-dibutyl itaconate-co-isoprene-co-methacrylic acid (a carboxylic elastomer) Silica grafted reduced graphene oxide Nanocomposites
Natural rubber	<ul style="list-style-type: none"> Epoxidized natural rubber Rubber composite with urazole group
Synthetic oils (usually petro-based products)	<ul style="list-style-type: none"> Neem oil Kurunj oil Vegetable oils (cashew nut, modified soybean) Organic clay Biodiesel
Activator (usually includes zinc oxide)	<ul style="list-style-type: none"> Carbon nanodots 2phr

alternatives for reducing the tyre rolling resistance using a bio-based carboxyl elastomer and modified rice husk ash.^{88,89} Such strategies are vital for BEVs to achieve the true label of ‘zero-emission vehicle’ when considering their life-cycle analysis.

Tyre Label – Easy to Read

The EU Regulation 2020/740 requires to follow a specific set of instructions for tyre labels.⁹⁰ There are

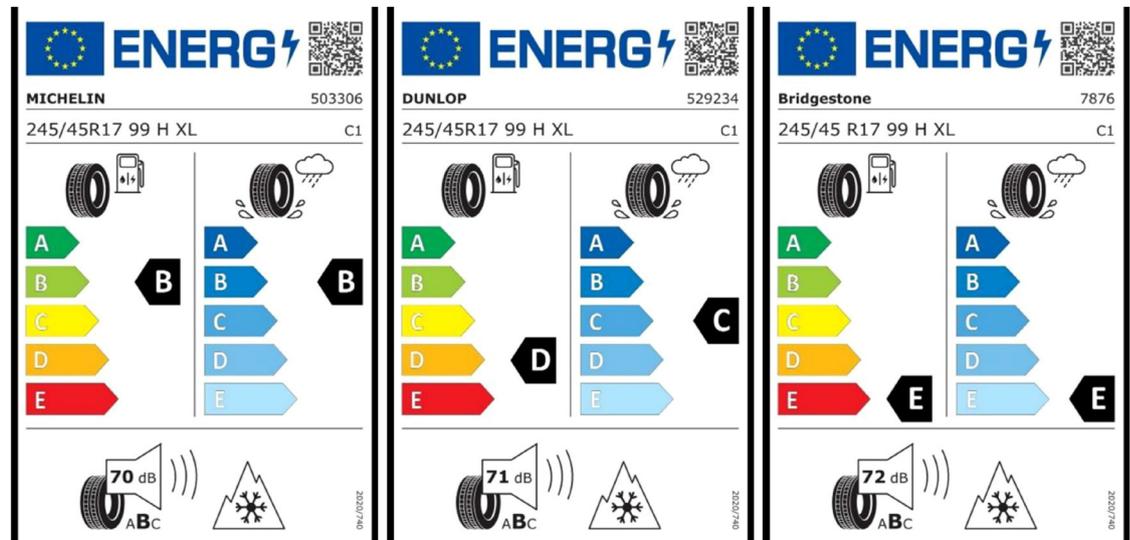


Fig 4 | Comparison of three winter tyre labels for an assumed EV in a hypothetical setting

five efficiency classes A-E, wherein A represents the highest class and E represents the lowest class. In each label, the manufacturer name, tyre size, and load specifications are listed on the upper-left corner. The scan code and the vehicle category (C1-Pascar, C2-LDV, C3-HDV) are located on the upper-right corner. In the middle, two columns are stacked side-by-side which includes a default multi-color list of the five classes A-E for fuel efficiency and wet grip capability. The actual class designated for the tyre is overlaid with a left side-pointing black arrow. The fuel efficiency class is determined based on the RR coefficient, with Class A representing tyres with the minimum RR and Class E representing those with the maximum RR. Therefore, class A tyres are expected to wear less and emit lesser tyre-induced microplastics compared to class E tyres. The latter wears more because of higher RR coefficient. Near the lower-left corner, the external noise level (dB) is typed inside the speaker followed by the noise class highlighted in the bold font. Finally, any special use cases such as severe snow or severe ice conditions are labeled with dedicated icons near the lower-right corner. Consider a scenario wherein the EV owner is given three choices (Premium/Super/Economy) by their service provider, as shown in Figure 4. For the same tyre sizing metrics (245/45R17) and load capacity (99 H XL) in the passenger car segment (C1), i.e., the parameters that matches the EV owner's vehicle model, the Michelin tyre would be a better selection (say 'Premium' trim) with respect to both performance and reduced emissions for assumed EV in winter. This is because of the low rolling resistance coefficient (fuel efficiency-B class), high traction coefficient (wet grip-B class), along with high noise attenuation (B class).

As discussed earlier, a low RR is expected to wear less, thereby emit less microplastics. The Bridgestone model may be the most affordable/'Economy' trim that the service provider would offer due to low capacities in range and traction. The Dunlop tyre would

be offered as an intermediate trim (say 'Super' trim). Notably, this is a hypothetical example based on data available in the EPREL website for a predefined set of classes and does not promote or discourage any tyre brands.⁹¹ The takeaway here is providing access to such pictorially represented labels, which allow the (EV) users to make informed decisions in picking less-wear tyres for increased driving range. Another item in the wish list would be to directly add a wear metric displaying the expected mileage or identifying it as well in the A-E class format, for instance, based on the test reports built up on the tyre abrasion method.⁷⁸

Conclusion

Microplastics is a hot topic in the environmental sciences, owing to its adverse health effects to the aquatic ecosystem and potentially to humans. Tyres contribute the majority of microplastic emissions according to various researchers and scientists. The vehicle and the tyre research community continue to use legacy emission factor models developed by pioneers of non-exhaust emission analyzers. These models used databases that are outdated by a decade or more; therefore, it may not accurately represent the current vehicles-in-use population in today's market. Especially, a significant difference will be seen in the share of electric vehicles in the passenger car market in 2023 when compared to 2013 (legacy model database).

These legacy models and subsequent studies who use them for reference made tyre wear projections for EVs by adding the battery mass to the equivalent ICEV. In contrast to this scenario, this article outlines several factors to consider while making assessments for tyre-induced wear/microplastics from EVs.

- To compensate for the additional weight of the EV battery, car makers may have incorporated lightweighting strategies via several changes in the EV's vehicle platform and in the materials selection.

- If a car maker replaces high-strength steel with alternative materials such as a mix of magnesium, aluminum, titanium, and carbon-fiber, a net gain of 25% weight savings is expected in the BEV, thereby matching the ICEV weight. If a car maker uses only magnesium and aluminum combinations, the corresponding BEV is expected to be lighter than the ICEV even with the battery included. These scenarios would alter the legacy analyses that BEVs emit more tyre emissions than ICEV.
- Another aspect is the EV-special tyres made to meet the targets of low rolling resistance, enhanced grip, and reduced noise. While these tyres are applicable to ICEVs as well in the current times of carbon dioxide reduction, these tyres may differ completely from the conventional tyres (used in ICEVs of the legacy models) in the way they react, form, and release microplastics. Therefore, testing actual BEVs with and without special tyres will provide a clear understanding and roadmap for future developments.

To this effect, a standard test procedure is needed for measuring tyre abrasion. With a placeholder for tyre wear measurements in the upcoming Euro 7, the status of related efforts on a test protocol is briefly reviewed. Tyre manufacturers may encourage their suppliers to investigate sustainable raw materials such as alternatives to carbon black or eco-friendly manufacturing techniques to make carbon black. As the BEV's range is extremely sensitive to the tyre inflation pressure, car makers may identify innovative tyre system solutions such as 'emergency-range' where the BEV can regain its available range only after inflating to the recommended level. Also, the tyre manufacturers and their dealers should strongly recommend usage of pictorial labels showing different (tyre) characteristics for the vehicle user to pick per their need. Adding a rating for the tyre abrasion in the same label would provide a comprehensive choice to the user. For this, however, all tyres should be evaluated following a standard test method which shall be validated for repeatability and reproducibility of the reported data. This article is believed to contribute in two ways: 1. Identifying the need to measure tyre abrasion of EVs using actual vehicle-tyre configurations. 2. If the results continue to show higher wear for BEVs compared to equivalent ICEVs, then it highlights the importance of business strategies for both car makers in terms of lightweighting components and for tyre manufacturers in identifying sustainable alternatives while maintaining performance targets. A few other topics of interest for tyre microplastics that are not included in the current work include effects of meteorological conditions, suitable particle sizing in spectroscopic analysis, and vehicle drive axle configurations.

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