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10th International Congress

Motor Vehicles & Motors 2024

ECOLOGY -
VEHICLE AND ROAD SAFETY
- EFFICIENCY

Proceedings

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October 10th - 11th, 2024
Kragujevac, Serbia

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PREDGOVOR

U oktobru se na Fakultetu inženjerskih nauka Univerziteta u Kragujevcu tradicionalno održava skup istraživača i naučnika koji se bave proučavanjem motornih vozila, motora i drumskog saobraćaja. Od 1979. do 2004. godine održano je trinaest bienalnih MVM simpozijuma koji su 2006. prerasli u Međunarodni kongres MVM. Od tada je održano devet MVM kongresa, a oktobra 2024. godine Fakultet inženjerskih nauka je organizovao deseti međunarodni kongres MVM od 10. do 11. oktobra 2024. godine.

Na deseti kongres Motorna vozila i motori, MVM2024 dostavljen je veliki broj naučnih radova iz Srbije i inostranstva. Kongres tradicionalno podržavaju Ministarstvo za nauku, tehnološki razvoj i inovacije Republike Srbije, Univerzitet u Kragujevcu, Fakultet inženjerskih nauka i međunarodni časopis „Mobility and Vehicle Mechanics“.

Tema Kongresa MVM 2024 bila je „Ekologija – Bezbednost vozila i na putevima – Efikasnost“. Tokom ovog istraživačkog putovanja, učesnici su puno naučili kroz rad na različitim sekcijama, koje su pokrivale širok spektar tema u vezi sa inženjerstvom u automobilskoj industirji, od fundamentalnih istraživanja do industrijskih primena, naglašavaju interakciju između vozača, vozila i životne sredine i stimulišući naučnu interakcije i saradnju.

Međunarodni naučni odbor u saradnji sa organizacionim odborom izradio je podsticajan naučni program. Program je ponudio preko 54 prezentacije radova, uključujući predavanja po pozivu i radove u sekcijama. Prezentacije na ovom kongresu obuhvatile su aktuelna istraživanja u oblasti motornih vozila i motora sprovedena u 12 zemalja iz celog sveta.

Zadovoljstvo nam je bilo što su nam uvodničari bili profesor Emrulah Hakan Kaleli (sa Tehničkog univerziteta Yıldız, Turska), profesor Ralph Putz (sa Univerziteta Landshut UAS, Nemačka) i profesori Nenad Miljić i Slobodan Popović (sa Univerziteta u Beogradu, Srbija). Izazovi i rešenja u korišćenju vodonika kao goriva za motore sa unutrašnjim sagorevanjem, korišćenje aditiva nanoborne kiseline dodatog u motorno ulje, kao i evropska politika o budućoj mobilnosti na putevima su bile teme uvodnih predavanja.

Sigurni smo da je ovaj program pokrenuo živu diskusiju i podstakao istraživače na nova dostignuća.

10. Kongres MVM 2024. finansijski je podržalo Ministarstvo za nauku, tehnološki razvoj i inovacije Republike Srbije.

Zahvaljujemo se iskusnim i mladim istraživačima koji su prisustvovali i prezentovali svoju stručnost i inovativne ideje na našem kongresu.

Posebnu zahvalnost dugujemo članovima međunarodnog naučnog odbora i svim recenzentima za njihov značajan doprinos visokom nivou kongresa.

Naučni i organizacioni komitet Kongresa MVM2024

FOREWARD

In October, the Faculty of Engineering University of Kragujevac traditionally holds gatherings of researchers and academics who study motor vehicles, engines and road traffic. From 1979 to 2004, thirteen, biennal MVM Symposiums have been held and they grew into an International Congress MVM in 2006. Since then, ninth MVM Congresses have been held, and in October 2024, the Faculty of Engineering organized the tenth International Congress MVM from 10th to 11th October 2024.

A large number of scientific papers from the Serbia and abroad were submitted to the tenth Congress "MVM2024". Congress is traditionally supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, University of Kragujevac, Faculty of Engineering and the International Journal "Mobility and Vehicle Mechanics".

The theme of the Congress MVM 2024 was "Ecology - Vehicle and Road Safety - Efficiency". Along this journey we learned from the various sessions, which broadly cover a wide range of topics related to automotive engineering from fundamental research to industrial applications, highlight the interaction between the driver, vehicle and environment and stimulate scientific interactions and collaborations.

The International Scientific Committee in collaboration with the Organising Committee built up a stimulating scientific program. The program offered over 54 presentations, including key-note speakers and paper sessions. The presentations to this conference covered current research in motor vehicle and motors conducted in 12 countries from all over the world.

We were pleased to have professor Emrullah Hakan Kaleli (from Yıldız Technical University, Türkiye), professor Ralph Pütz (from Landshut University UAS, Germany) and professors Nenad Miljić and Slobodan Popović (from University of Belgrade, Serbia) as the keynote speakers, addressing Challenges and solutions in using hydrogen as a fuel for internal combustion engines, using nanoboric acid (nBA) additive added in engine oil, as well as European policy on future road mobility.

We are sure this program will trigger lively discussion and will project researchers to new developments.

The 10th Congress MVM 2024 was financially supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia.

We would like to thank experienced and young researchers, for attending and bringing their expertise and innovative ideas to our conference.

Special thanks are due to the International Scientific Board Members and all reviewers for their significant contribution in the high level of the conference.

Scientific and Organizational committee of Congress MVM2024

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International Congress
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Motor Vehicles & Motors

MVM2024-011

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TIRE WEAR: VEHICLE SAFETY AND ENVIRONMENTAL PROBLEM

ABSTRACT: The vehicle consists of a large number of elements that make it safe and prevent traffic accidents. One of the important elements on the vehicle are tires. Tires are one of the key elements on a vehicle that prevent the occurrence of a traffic accident, bearing in mind that they are the only contact between the vehicle and the ground. The wear of tires or their tread basically has two key problems that occur. The first problem is the problem of vehicle safety, with the reduction of the depth of the pattern or tread of the tire, the characteristics of the tire decrease. These characteristics are primarily related to the fact that in some cases the braking distance of the vehicle is extended, the adhesion between the tire and the surface is reduced in the case of wet pavement, ... Another problem is an environmental problem that occurs due to tire wear. Tire wear leads to the formation of particles. Tires consist of different materials, and their wear and tear and the formation of particles contain materials that can be harmful to humans and the environment. In this paper, tire wear is analyzed from the aspect of vehicle safety and ecology, where the pollution caused by the wear of vehicle tires is analyzed.

KEYWORDS: Vehicle, tires, safety, ecology.

INTRODUCTION

Pneumatics (tires) on motor vehicles is one of the most important elements on the vehicle when it comes to vehicle safety. Tires represent elements that have the only contact with the surface [1]. Thus, tires represent an important element from the aspect of vehicle safety. The braking distance of the vehicle depends on the tires, but also the

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stability of the vehicle during its movement. Today, there are a number of different types of tires that differ according to their names, construction or composition, depending on the purpose. Also, tires have their own characteristics related to driving conditions, their behavior on the road in different driving conditions, the level of noise created and the impact of fuel consumption [2]. One of the basic divisions of tires is according to the weather conditions in which they are used. According to this classification, the first type are winter tires, which are used in the winter months and in bad road conditions. Summer tires are used in the summer months and in better weather conditions and can be used in the rain and at temperatures above 7°C. The third group of tires is all-season tires, which are a compromise between summer and winter tires and can be used in almost all conditions. These tires are designed differently according to the tread and the tire itself consists of a mixture of different materials. Applications in conditions for which the tires are not designed can lead to a negative effect on the braking distance and behavior of the tires [3].

The problem that occurs with tires is their wear. Tire wear leads to two basic problems. The first problem that occurs during wear is the pollution of the environment by particles that are created during tire wear. In jargon, pneumatics are often called tires, however, the tread consists of a mixture of different materials. During the movement of the vehicle, wear of the tread occurs in the form of particles of different sizes. Another negative phenomenon that occurs with tire wear is the reduction of the tread, i.e. the pattern on the tread. By reducing the tread, the characteristics of the tires are reduced and lead to a negative effect on the braking distance [4].

In this paper, an analysis and review of other results related to the impact of different characteristics of tires from the aspect of safety, as well as an analysis of the formation of particles resulting from tire wear, was performed. The impact of tires on vehicle safety and above all on braking distance was analyzed with several characteristics such as tire tread depth, tire type from the aspect of weather conditions for which the tire was designed, tire pressure, etc. The impact of tires on the environment is also analyzed in this paper, as well as the overall impact of tires on the environment in relation to other pollutants.

INFLUENCE OF TIRES ON VEHICLE SAFETY

The influence of the type of tire according to its purpose on the braking distance of the vehicle

It was noted that tires can differ according to their purpose in different climatic conditions, that is, when the vehicle moves in different road conditions. Thus there are so-called winter tires, summer tires and all-season tires. According to the legislation of the Republic of Serbia, it is mandatory to use winter tires in the period from November 1st to April 1st if there is ice, snow or ice on the road. However, if the road is dry, it is allowed to use summer tires. The problem that can arise then is the ambient temperature. Summer tires have uniform characteristics up to a temperature of 7°C, if the temperature is lower they become rigid, which has a negative effect when braking. So you have to take that into account, so if the temperature during the day is higher, you can use summer tires, but in this period, if the temperature is lower, you still need to use winter tires, whose characteristics do not change below the specified temperature. Figure 1 shows the level of tire compatibility depending on the external temperature and climatic conditions.

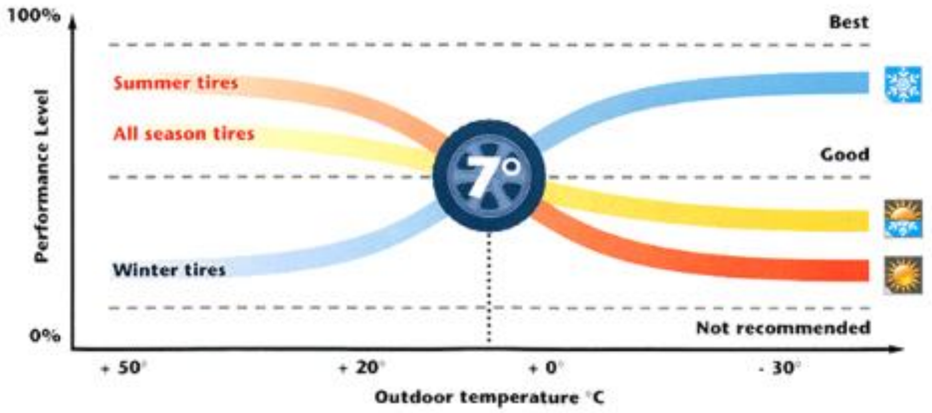
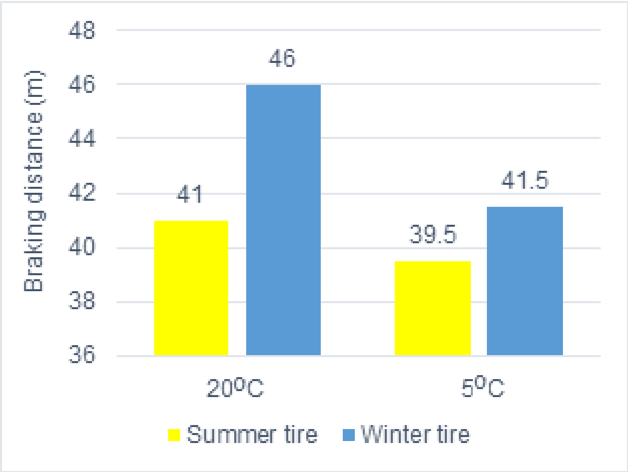


Figure 1 Tire compatibility level depending on ambient temperature [5]

The influence of the ambient temperature on the tires and finally the stopping distance is shown in Figures 2 and 3. Figure 2 primarily shows the influence of the ambient temperature depending on the tires and on dry and wet pavement. It can be seen that the stopping distance differs significantly from the temperature and road conditions. In the case of dry pavement and when the temperature is higher than 20°C, in that case it is unfavorable to use winter tires because the braking distance increases significantly. Summer tires, on the other hand, showed favorable characteristics at all temperatures and when the pavement is dry. In the case of wet pavement, the use of summer tires at a temperature of 5ºC is very unfavorable because the braking distance is significantly extended compared to a temperature of 20ºC. The displayed data is related to braking at an initial speed of 100 km/h. Figure 3 shows the values of the braking distance depending on the conditions and the tire used, where it can be seen that at a temperature of 15ºC and on dry and wet pavement, summer tires have the shortest braking distance, all season and winter tires. In snow conditions, winter, all-season and summer tires have the shortest braking distance.

a)


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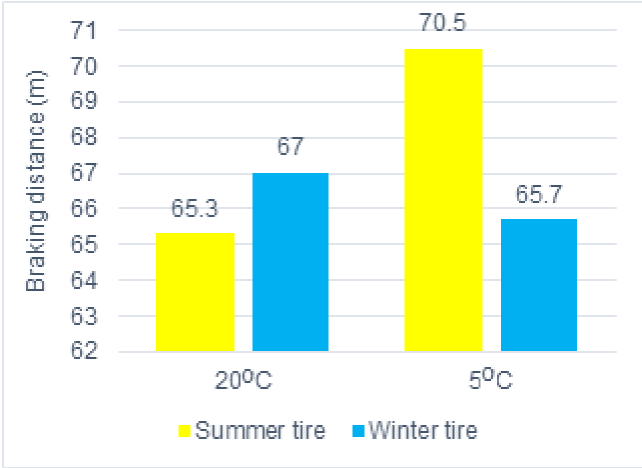


Figure 2 Braking distance from 100 km/h to 0 km/h depending on tires and ambient temperature, a) braking on dry pavement, b) braking on wet pavement [6,7]

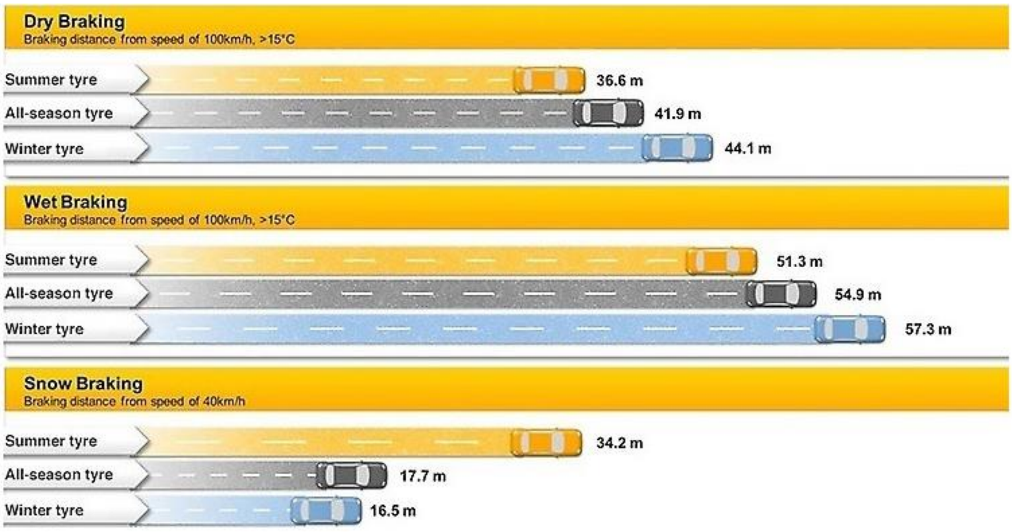
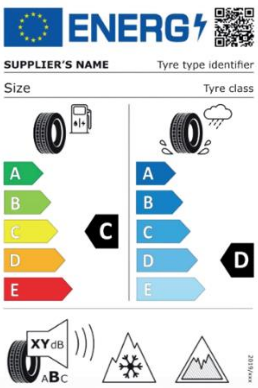


Figure 3 Dependence of braking distance on tires and braking conditions [8]

From May 2021, all tires have their own markings or EU tire label related to tire application, fuel consumption, i.e. economy, noise level, but also wet grip rating, such a marking is shown in Figure 4a. The wet grip rating is further linked to the stopping distance. The difference of the braking distance depending on the grip distance rating depending on the category is shown in Figure 4b. Tires with category F tires have 18 m longer stopping distance compared to tires with category A.

a)


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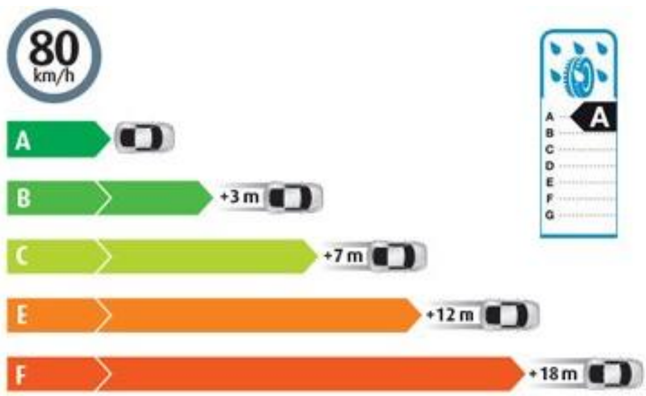


Figure 4 EU tire label and the influence of the category on the braking distance on wet roads: a) the appearance of the tire label, b) the difference in the length of the braking distance of different categories [9, 10]

Tires also have an impact on the vehicle's ability to turn. Figure 5 shows the possibility of turning the vehicle when moving the vehicle on snow. It is noticeable that winter tires have the best and more favorable turning, followed by all-season tires, and summer tires have the worst turning angle, at least when turning on snow.

Figure 5 The influence of the type of tire on the cornering of the vehicle [11]

Effect of tire tread depth on braking distance

The depth of the tire tread is one of the important elements when it comes to the influence of the tire on the stopping distance of the vehicle. Minimum tire tread depth values are legally prescribed. There is a significant influence of the depth of the pattern on the stopping distance, so as shown in Figure 6, as the depth of the pattern decreases, the stopping distance increases. Thus, it is necessary to always take care of tire wear because new tires have a significantly shorter braking distance compared to worn tires.

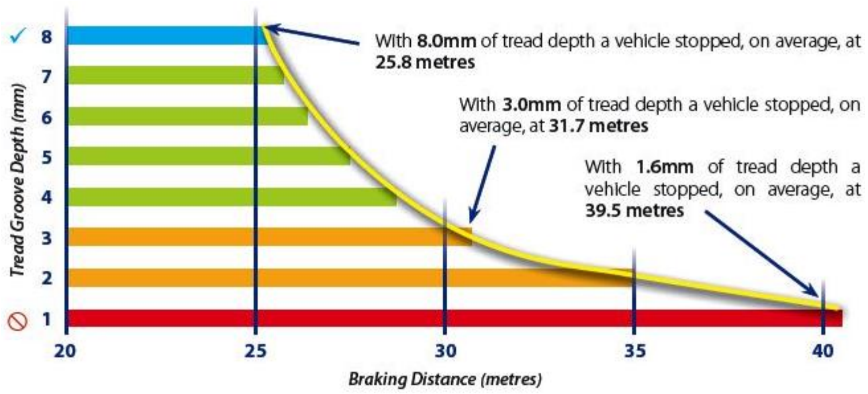


Figure 6 The length of the braking distance depending on the depth of the tire tread [12]

As mentioned, the depth of the pattern has a significant influence on the stopping distance, but it must be noted that the impact of the stopping distance also depends on the manufacturer. Figure 7 shows the background paths of two tires from different manufacturers in the case of new and worn tires. It is noticeable that there is a difference in the stopping distance even with new tires, but they also differ when the tires are worn. If the tires are analyzed according to the manufacturers, it is noticeable that in the case of some tires, when the tires wear out, the stopping distance increases significantly. There is always an increase in braking distance, but with some tires that distance increases significantly.

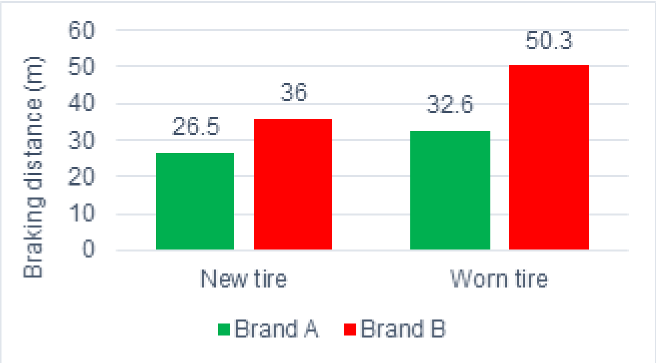
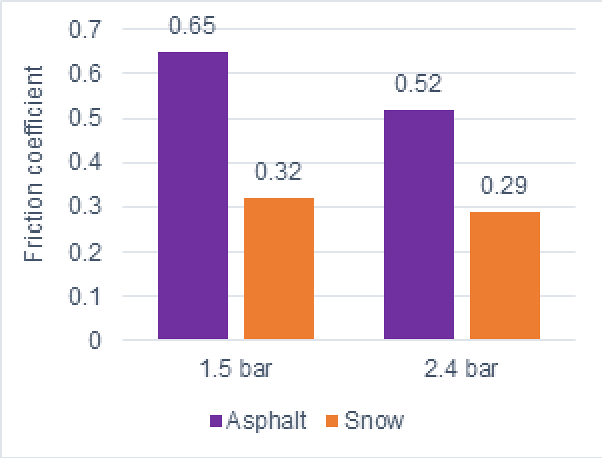


Figure 7 The length of the braking distance in the manufacturer and the condition of the tires [13]

Influence of tire pressure on braking distance

When it comes to braking, tire pressure is an important factor. In the study [14], different tires and pressure were shown, where it was shown that they have a different effect on the stopping distance, but that they differ according to the type of tire. Figure 8a shows the influence of tire pressure on the friction coefficient depending on the surface. When it comes to stopping distance, it is noticeable that the stopping distance is longer when the pressure in the tire is higher. Which can be related to the surface of the tire tread.



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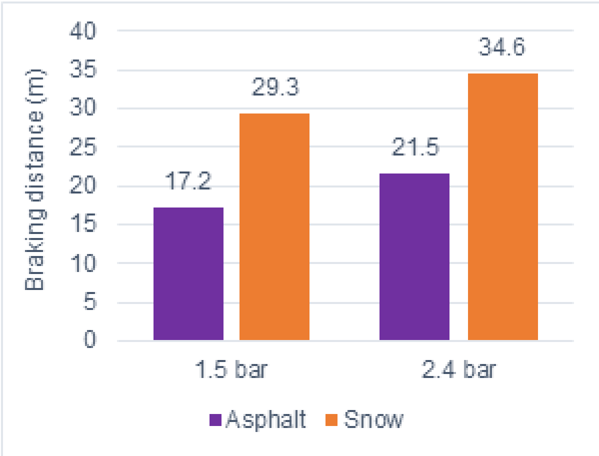


b)

Figure 8 Braking distance depending on tire pressure and road conditions: a) coefficient of friction, b) stopping distance [15]

Figure 9 shows the values of the stopping distance at different pressures and road conditions. Thus, the shortest braking distance is at medium pressure, while at the lowest and highest pressure. Thus, it can be concluded that neither the highest, nor the lowest pressures are the most favourable. It is recommended that the pressure be the one prescribed by the manufacturer.

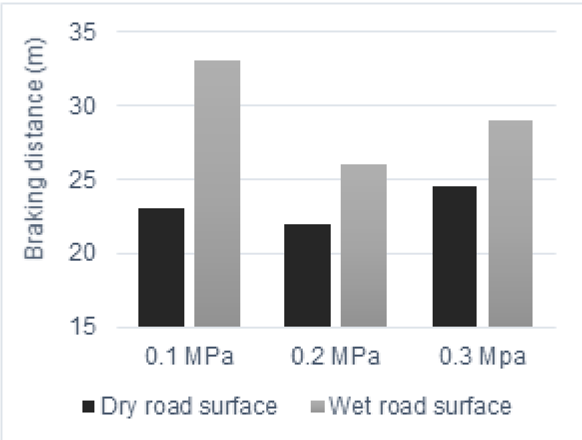
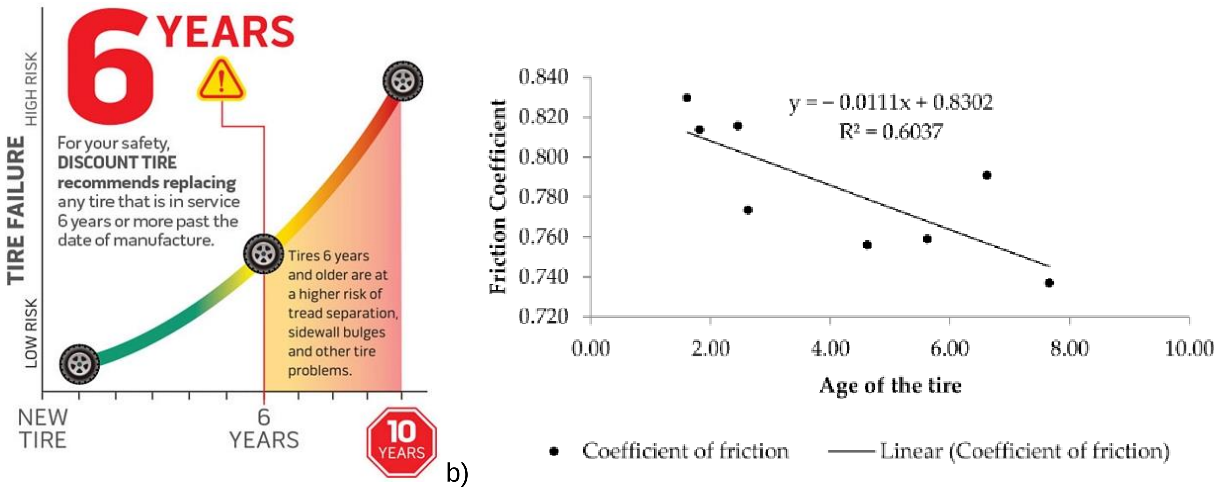


Figure 9 Braking distance depending on tire pressure and road conditions [16]

Effect of tire age on braking distance

It is known that each tire has its own year of production. As the tire ages, the characteristics of the tire deteriorate due to oxidation or other effects on the materials from which the tire is made. Figure 10a shows the recommendation that as tires age, the risk of tire failure increases. It is recommended not to use tires older than six years. Figure 10b shows that as the tire ages, the adhesion coefficient decreases. This was determined by applying a correlation where it was observed that there is a negative correlation between the coefficient of friction and the age of the tire. Due to the age of the tires, their oxidation occurs or the tire becomes stiff. In this case, cracks may form on the tire. It is certainly necessary to check the age of the tires through the so-called DOT number that is written on each tire. In addition to all the information, the DOT also contains information about the year of manufacture and the week of the year in which the tire was manufactured. Thus, there are recommendations to change tires every six years from the date of manufacture, but it is also recommended to never operate and use tires that are older than ten years.



a) b)

Figure 10 Tire age and influence on the friction coefficient: a) Dependence of tire age and tire failure, b) Correlation between tire age and friction coefficient [16, 17]

IMPACT OF TIRES ON THE ENVIRONMENT

The life of a tire is determined by its age or tread depth. After a certain number of years, when the tire exceeds the limit mentioned in the previous section, when the depth of the tread pattern falls below the permitted limit or due to damage, it is no longer usable; it can be treated as waste. When looking at the number of tires that are discarded in just one year, they become a global problem of environmental pollution [19]. According to data [20], over 280 million tires are discarded every year, of which around 30 million are remanufactured so that they can be reused, while 250 million tires remain as waste. Thus, one of the ways to reduce harm to the environment is the recycling of tires for reusing materials or generating energy [21]. The problem that occurs with tires is that tires are not biodegradable, so they do not break down in nature like some natural materials, so they can only pile up when dumped in nature. They are also very durable and can pile up and take up a lot of space in landfills. Therefore, this option of their disposal has always raised a question mark for decades. Figure 11 shows the process of tire production and recycling. However, in recent times, manufacturers are finding more and more uses for scrap tires such as in construction, retaining walls, creating highway barriers and lightweight construction materials in urban transport infrastructure projects. Companies are working to create biodegradable prototypes and sustainable tires [22].

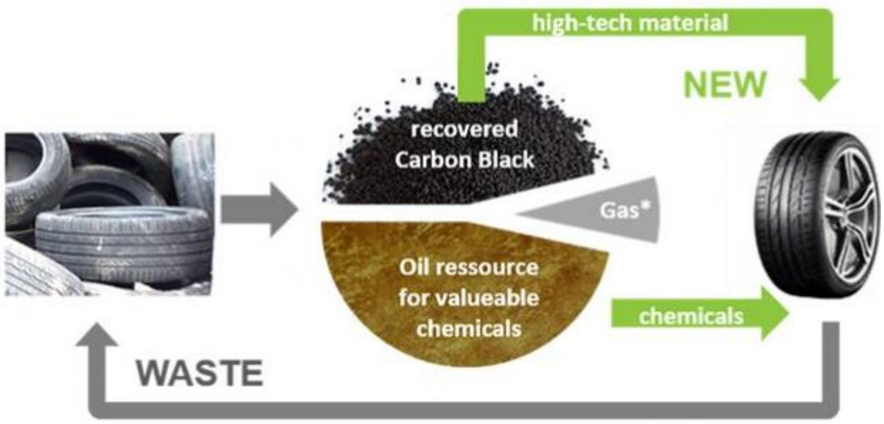


Figure 11 A simplified tire production and recycling process [22]

The phenomenon that leads to tires not having sufficient tread depth is tire wear. Tire wear is a process in which the pattern loss occurs due to the formation of small particles. That is, the worn material is thus released into the environment in the form of particles known as PM particles. Just like brakes, tires belong to non-exhaust sources of particles, i.e. environmental pollutants, which pollute the environment through wear. Figure 12 shows how particles are formed by tire wear. The particles produced by tire wear contain materials that are part of the tire, according to [23] the dominant materials in tire particles are Si, Zn, and S. Based on [24], it can be concluded that the composition of particles depends on the size of the particles, thus $PM_{2.5}$ particles contain Zn, Cu, S, Si and organic carbon, while PM_{10} particles contain Zn, Cu, Si, Mn. In the research [25], it was shown that the particles produced by tire wear are recognized as microplastics and that tire wear is the main factor that contributes to the emission of microplastics into the environment. According to a study [26] that analysed microplastics within the tributaries of the Charleston Harbor estuary, South Carolina (USA), tire wear particles were observed to be one of the most abundant types of microplastics. Based on [27], more than 0.5 million tons of particles are annually emitted in Europe, i.e. 6 million tons are broadcast worldwide. Tire particles are formed due to shear forces between the tread and the road. On average, tire particles contribute about 5% of atmospheric PM concentrations, and studies show values between 0.2% and 22% depending on different parameters [27]. According to the studies [28, 29], tires emit pollutants via atmospheric, water and land routes. Thus, tires represent a complex source of pollutants, including whole tires, particles, compounds and chemicals [28]. When it comes to the impact on human health, according to [30], it is stated that the impact on health is currently poorly researched or documented, but they represent a health and environmental risk [29].

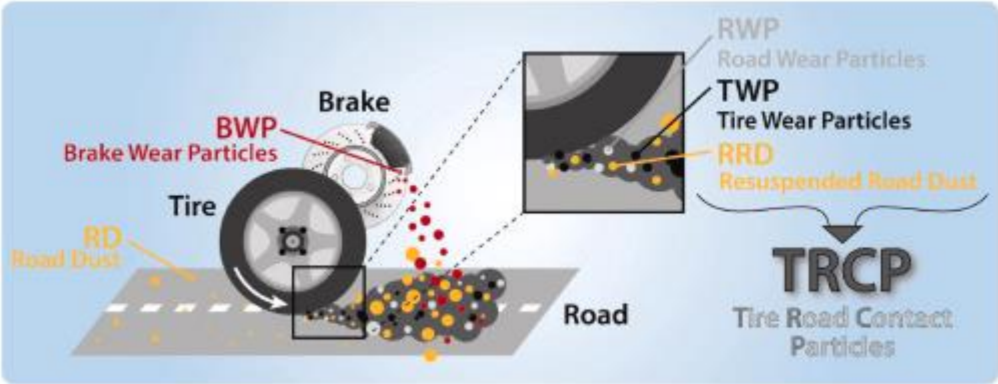
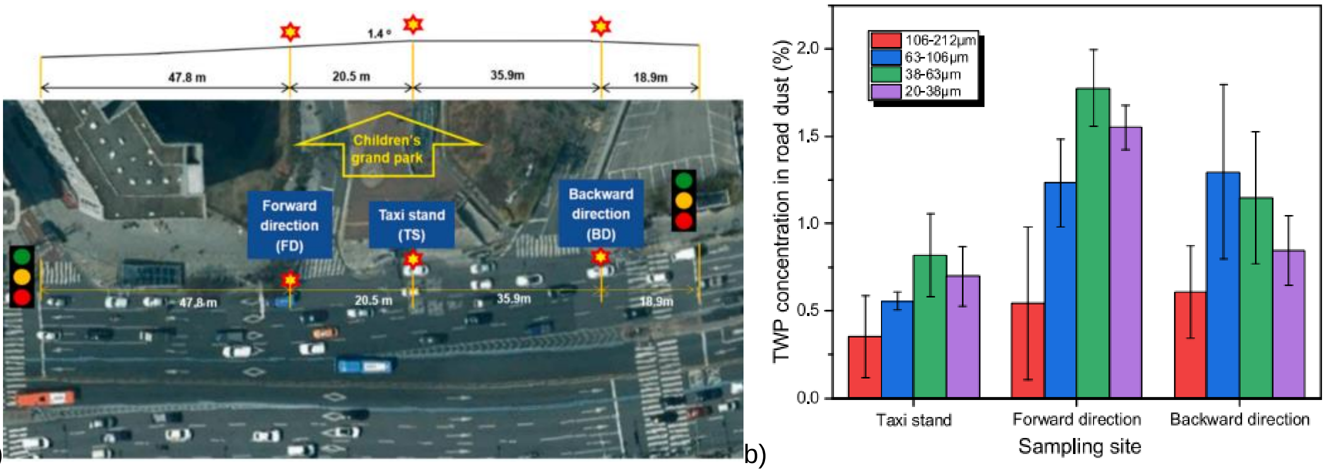


Figure 12 Tire wear and the formation of particles from various vehicle elements [27]

In addition to particle composition, size is also a significant factor that affects health and the environment. Smaller diameter particles can have a greater impact on the environment as well as on human health. According to research [31], it was determined that 94.80% of the particles produced by tire wear are 6 nm to 10 μm in size. In the research [32], trackers that attach to particles were monitored according to the source, i.e. brakes and tires. It was observed that the size of the particles in the composition of the tire wear trackers had a peak size of 10 μm to 18 μm. In the research [33], the sizes of the particles produced by tire wear on the side of the road were analysed, as shown in Figure 13. Particles with a larger diameter were analysed in one street and in three locations. Larger particle sizes were observed, while the concentration varied with respect to the measurement location. It has been shown that the emission of tires participates with 5% to 30% percent in the total emission, while the highest mass concentration is at the particle size in the case of 20 μm and 100 μm, as well as at sizes from 2 μm to 10 μm [34].

a)


b)

Figure 13 Measurement of the emission of particles produced by tire wear, a) measurement locations, b) measurement results [33]

Research on the emission of particles caused by tire wear can be carried out in several ways, in the laboratory or on-road research. In the case of road research, it is more difficult to measure the emission of tire particles because it is difficult to separate them from particles that are not a product of tire wear or that are a product of tire wear but from other vehicles that were moving on the road [35]. When it comes to road tests, devices and equipment must generally be added to the vehicle that would collect particles or draw particles into a device for their measurement and analysis. Figure 14 shows some of the solutions that were used to measure and analyse particles that are produced by tire wear. As can be seen, near the contact between the wheel and the surface, i.e. at the exit from that contact on the rear side of the tire, a device is installed whose role is precisely to collect particles. Different researchers have used different but very similar solutions for the purpose of this measurement. Again, as a disadvantage, it is necessary to state that such measurements are very complicated, because when collecting or drawing in particles, other particles are also collected that were not formed during the wear of the used tire. In relation to brakes and measurements of the emission of brake particles, it is not possible here or the solutions are more complicated to ensure only the collection of particles that arise in the subject research. In the case of brake emissions, the aim is for the brake to be isolated by a special housing.

Figure 14 Variants of devices on vehicles for drawing in and measuring particles produced by tire wear in case of road tests, a) first variant, b) second variant, c) third variant [36, 37, 38]

Application of a real vehicle is also possible in laboratory conditions for testing the formation of particles during tire wear. In the case of the chassis dynamometer, where a real vehicle is applied, as shown in Figure 15. In this case, the vehicle moves on rollers that simulate the road, i.e. the movement of the vehicle on the road. In this case, the test is carried out in a laboratory, so it is easier to separate the tire wear particles from the particles that result from the wear of other elements. The Figure 15 shows a view of the test as well as the measuring installation and the setting of the measuring device in relation to the tire.

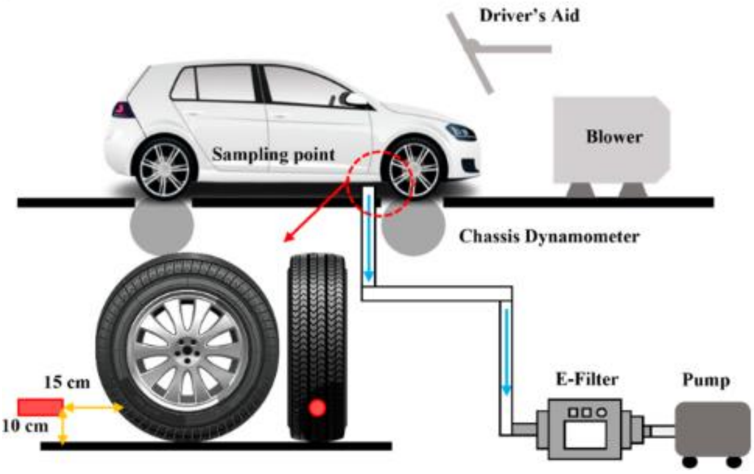


Figure 15 Examination of particle emissions caused by tire wear on a chassis dynamometer [39]

Application of a dynamometer and testing of tire wear without a real vehicle is also possible, as is the measurement of particle emissions caused by brake wear. Figure 16 shows different variants of tire wear tests using a dynamometer, where only the wheel is used and the movement of the vehicle on the road is simulated. It is noticeable that in each case, the tire load and its movement on the road are simulated. In this case, the road is simulated over a large-sized wheel that is coated with an asphalt surface or has asphalt characteristics. In some cases, as in brake emission testing, the wheel can be closed in the housing, where only the concentration of particles resulting from tire and road wear can be measured.

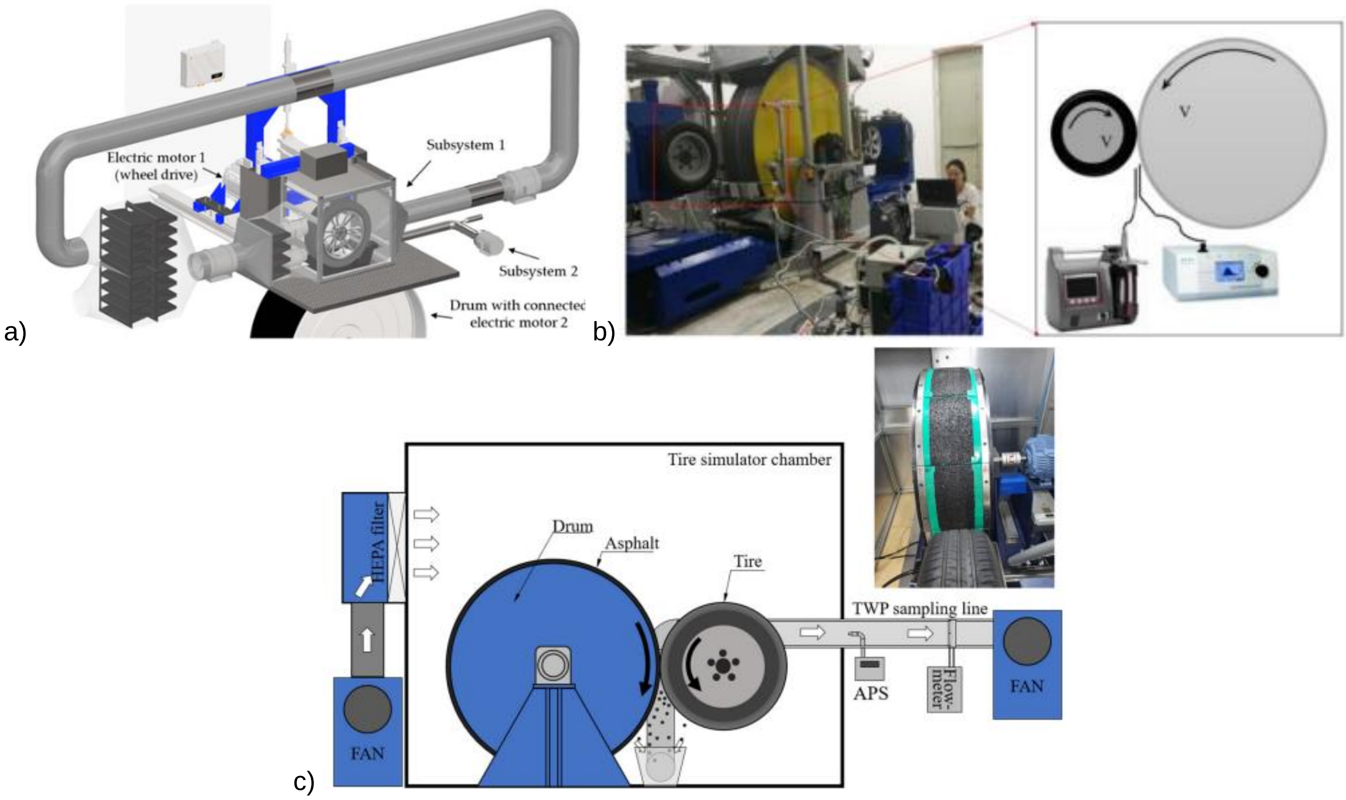


Figure 16 Examination of the emission of particles produced by tire wear in laboratory conditions [23, 35, 40]

CONCLUSIONS

Tires are an important element on a motor vehicle when it comes to vehicle safety. There are factors that can affect primarily the stopping distance of the vehicle and the turning of the vehicle when it comes to the characteristics of the tires. There are different tires that have different purposes when it comes to the conditions in which they are used. The use of tires in conditions for which they are not intended can extend the braking distance and endanger traffic safety. The characteristics of the tires change during the operation of the vehicle and in different time intervals. Thus, it is necessary to take care of the depth of the tread pattern, because tire wear can lead to a negative effect when it comes to braking distance. Over time, there are also changes in the characteristics of the material, so it is necessary to take into account the year of manufacture and the age of the tire, because the braking distance is also negatively correlated with the braking distance, so with the increase in the age of the tire, the braking distance also increases, or has an impact. Of course, such characteristics and the exact braking distance differ from manufacturer to manufacturer. When buying tires, it is necessary to pay attention to the categorization and characteristics of the tires based on the markings given by the manufacturer. First of all, when it comes to vehicle safety, it is necessary to take into account the class of tires according to the adhesion coefficient on wet pavement. The lowest classes have a worse braking distance on wet pavement compared to the classes of the higher category. Tire maintenance is also important at least when it comes to tire pressure. It is necessary to always maintain the pressure prescribed by the vehicle or tire manufacturer, otherwise the braking distance may be significantly longer.

Environmental pollution when it comes to tires is also a dominant problem. Tire wear leads not only to a reduction in vehicle safety, but also to environmental pollution. Tire wear occurs gradually because tire wear occurs when moving and braking. In the case of tire wear, there is the creation of particles that are micrometer in size and even smaller. These particles have a very small diameter, so they easily reach the environment and the human body. In addition to the size of the particles, the problem is also the composition of those particles. Tires consist not only of rubber but of a mixture of different materials in order to have satisfactory characteristics. Thus, these materials are also released into the environment in the form of particles, so these particles are also very small. With the increase in the number of vehicles and tires, the problem of pollution is getting bigger. Also a problem today are tires that are no longer usable due to the age of use or wear and tear, so in addition to particle pollution, they pollute when they leave.

Testing of particle emissions is carried out today using different methods, and most often it is the road tests or some variant of laboratory testing. Each methodology used for testing has its advantages and disadvantages. Real road tests and dynamometer tests, where the vehicle and wheel movement on the road are simulated, are most often used for tire emissions. Methodologies for testing the emission of particles resulting from tire wear will be the subject of subsequent research.

REFERENCES

[1] Li, T: “Literature review of tire-pavement interaction noise and reduction approaches”, Journal of Vibroengineering, 20,6, 2018, 2424-2452.
[2] Tire Safety and Maintenance, https://michelinmedia.com/site/user/files/1/016---Unit-14-Tire-Safety.pdf, accessed 04.07.2024.
[3] Mitchel, L.: “Tyre Particle Health, Environment and Safety Report”, Tyre Stewardship Australia, 2022.
[4] Jansen, S., Schmeitz, A., Akkermans, L.: “Study on some safety-related aspects of tyre use”, European Commission, 2014, Brussels, Belgium, MOVE/C4/2013-270-1.
[5] SPRING 2016: When is the ideal time to remove winter tires?, https://georgetownvw.wordpress.com/2016/03/17/spring-2016-when-is-the-ideal-time-to-remove-winter-tires/, accessed 08.07.2024.
[6] Road Test Special – Winter Tires Vs. All-Season Tires. Is Your Car Ready For Winter?, https://roadtestdotorg.wordpress.com/2016/11/07/road-test-special-winter-tires-vs-all-season-tires-is-your-car-ready-for-winter/, accessed 08.07.2024.
[7] Comparation of temperature dependent brake distance, https://www.tyresafe.org/tyre-advice/all-season-tyres/winter-tyre-safety/, accessed 08.07.2024.
[8] Winter vs summer tyres – understand the differences, https://bestdrive.ie/news/winter-vs-summer-tyres-understand-differences/, accessed 08.07.2024.
[9] EU Tyre Label, https://www.goodyear.eu/en_za/consumer/learn/eu-tire-label-explained.html, accessed 20.07.2024.
[10] Tyre labels : Fuel efficiency, grip and rolling noise, https://www.tyreleader.co.uk/tyres-advices/car-tyres-label#wet, accessed 20.07.2024.
[11] Summer vs all-season vs winter tires, https://www.cjponyparts.com/resources/summer-all-season-winter-tires-infographic, accessed 20.07.2024.
[12] Our Pick of the Best 4WD Tyreshttps://www.fleetcrew.com.au/best-4wd-tyres/, accessed 23.07.2024.
[13] Tire performance over life time: Wet braking, https://toptirereview.com/tire-performance-over-life-time-wet-braking/, accessed 23.07.2024.
[14] Stoklosa, J., Bartnik, M.: „Influence of tire pressure on the vehicle braking distance“, The Archives of Automotive Engineering - Archiwum Motoryzacj, 97, 3, 2022, 60-73.
[15] Radu, A. I., Trusca, D., Toganel, G.: „Influence of tire pressure on the braking distance when driving on snow and asphalt“, IOP Conf. Series: Materials Science and Engineering, 444, 2018, 072013.
[16] Hadryś, D., Węgrzyn, T., Miros, M.: “The influence of various pressures in pneumatic tyre on braking process of car with anti-lock braking system“, Transport problems, 3, 1, 2008, 85-94.
[17] Tire Safety Practices, https://www.discounttire.com/learn/tire-safety, accessed 28.07.2024.
[18] Lorenčić, V.: “The Effect of Tire Age and Anti-Lock Braking System on the Coefficient of Friction and Braking Distance”, Sustainability, 15, 8, 2023, 6945.
[19] Kang, G.S., Lee, G., Cho, S. Y., Joh, H.I., Lee, D. C., Lee, S.: “Recycling of waste tires by synthesizing N-doped carbon-based catalysts for oxygen reduction reaction”, Applied Surface Science, 548, 2021, 149027.
[20] The current state of global tyre recycling: facts and figures, https://gradeall.com/the-current-state-of-global-tyre-recycling-facts-and-figures/#:~:text=Each%20year%2C%20over%20280%20million,million%20–%20are%20retreaded%20or%20reused, accessed 01.08.2024.
[21] Pavlović, A., Nikolić, D., Jovanović, S., Bošković, G., Skerlić, J.: „Life cycle assessment of the car tire with eco indicator 99 methodology“, Mobility & Vehicle Mechanics, 45, 3, 2019, 13-23.
[22] What Happens to Old Tyres After They Are Discarded, https://www.tyremarket.com/tyremantra/happens-old-tyres-discarded/, accessed 01.08.2024.
[23] Beji, A., Deboudt K., Muresan B., Khardi S., Flament, P., Fourmentin, M., Lumiere, L.: “Physical and chemical characteristics of particles emitted by a passenger vehicle at the tire-road contact”, Chemosphere, 340, 2023, 139874.
[24] Grechkin, A., V., and Kotliarenko, I. V.: “Assessment of the composition of solid particle emissions from tire and roadway wear that pollute the atmosphere of large cities”, IOP Conf. Series: Earth and Environmental Science, 867, 2021, 012095.
[25] Knight, L.J., Parker-Jurd, F.N.F., Al-Sid-Cheikh, M., Thompson, C. R.: “Tyre wear particles: an abundant yet widely unreported microplastic?”, Environmental Science and Pollution Research, 27, 2020, 18345–18354.
[26] Leads, R. R., Weinstein, J. E.: “Occurrence of tire wear particles and other microplastics within the tributaries of the Charleston Harbor Estuary, South Carolina, USA”, Marine Pollution Bulletin, 145, 2019, 569–582.
[27] Giechaskiel, B., Grigoratos, T., Mathissen, M., Quik, J., Tromp, P., Gustafsson, M., Franco, V., Dilara, P.: “Contribution of Road Vehicle Tyre Wear to Microplastics and Ambient Air Pollution”, Sustainability, 16, 2, 2024, 522.
[28] Mayer, P. M., Moran, K. D., Miller, E. L., Brander, S. M., Harper, S., Garcia-Jaramillo, M., Carrasco-Navarro, V., Ho, K. T., Burgess, R. M., Hampton, L. M. T., Granek, E. F., McCauley, M., McIntyre, J. K., Kolodziej, E. P., Hu, X., Williams, A. J., Beckingham, B. A., Jackson, M. E., Sanders-Smith, R. D., Fender, L. C., Mendez, M.: „Where the rubber meets the road: Emerging environmental impacts of Tire Wear particles and their chemical cocktails”, The Science of the Total Environment, 927, 2024, 171153.

[29] Parker-Jurd, F. N. F., Napper, I. E., Abbott, G. D., Hann, S., Thompson, R. C.: “Quantifying the release of tyre wear particles to the marine environment via multiple pathways”, Marine Pollution Bulletin, 172, 2021,112897.
[30] Bouredji, A., Pourchez, J., Forest, V.: “Biological effects of Tire and Road Wear Particles (TRWP) assessed by in vitro and in vivo studies – A systematic review” The Science of the Total Environment, 894, 2023, 164989.
[31] Zhong, C., Sun, J., Zhang, J., Liu, Z., Fang, T., Liang, X., Yin, J., Peng, J., Wu, L., Zhang, Q., Mao, H.: “Characteristics of Vehicle Tire and Road Wear Particles’ Size Distribution and Influencing Factors Examined via Laboratory Test”, Atmosphere, 15, 2024, 423.
[32] Lopez, B., Wang, X., Chen, L.-W. A., Ma, T., Mendez-Jimenez, D., Cobb, L. C., Frederickson, C., Fang, T., Hwang, B., Shiraiwa, M., Park, M., Park, K., Yao, Q., Yoon, S., Jung, H.: “Metal contents and size distributions of brake and tire wear particles dispersed in the near-road environment”, Science of The Total Environment, 883, 2023, 163561.
[33] Chae, E., Jung, U., Choi, S.S.: “Types and concentrations of tire wear particles (TWPs) in road dust generated in slow lanes”, Environmental Pollution, 346, 2024, 123670.
[34] Giechaskiel, B., Grigoratos, T., Mathissen, M., Quik, J., Tromp, P., Gustafsson, M., Franco, V., Dilara, P.: “Contribution of Road Vehicle Tyre Wear to Microplastics and Ambient Air Pollution”, Sustainability, 16, 2024, 522.
[35] Hesse, D., Feißel, T., Kunze, M., Bachmann, E., Bachmann, T., Gramstat, S.: “Comparison of Methods for Sampling Particulate Emissions from Tires under Different Test Environments”, Atmosphere, 13, 2022, 1262.
[36] Hesse, D.: “Beitrag zur Experimentellen und Analytischen Beschreibung Partikelförmiger Bremsenemissionen”, Ph.D. Thesis, Technische Universität Ilmenau, Ilmenau, Germany, 2020.
[37] Schmerwitz, F., Wieting, S., Aschenbrenner, N., Topp, A., Wies, B.: “Characterization of Tire Road Wear Particles in the Field and at Laboratory Scale”, 12th International Munich Chassis Symposium 2021, 2022, 729-743.
[38] Andersson, J., Campbell, M., Marshall, L., Kramer, L., Norris, J.: “Measurement of emissions from brake and tyre wear”, Final Report – Phase 1, Ricardo Energy & Environment, Report for Department for Transport, 2023, T0018 - TETI0037.
[39] Li, J., Zhang, M., Ge, Y., Wen, Y., Luo, J., Yin, D., Wang, C., Wang, C.: “Emission Characteristics of Tyre Wear Particles from Light-Duty Vehicles”, Atmosphere, 14, 2023, 724.
[40] Zhang, X., Chen, P., Liu, F.: “Review of Tires Wear Particles Emission Research Status”, IOP Conference Series: Earth and Environmental Science, 555, 2020, 012062.

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