Analysis of the quantity of particles emitted to the environment as a result of the brake linings wear of specialized transport vehicles

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Abstract. This article examines the composition of particles emitted into the environment as a result of brake lining degradation during the braking of specialized cars. The amount of particles emitted into the environment has been theoretically studied, taking into account that the resource duration of brake linings on specialized vehicles varies based on the adhesion coefficient of wheel contact with the road. The distribution of metal concentrations in particles created by the brake linings wear during the braking of specialized vehicles is extensively studied. Traffic-related sources contribute significantly to particulate matter in cities. It was discovered that the samples collected during the braking of specialized vehicles contain high levels of metal elements such as iron, copper, zinc, chromium, tin and antimony. Currently, there is information about the negative impact of the particles formed during braking of cars on the environment.

1 Introduction
as a result of brake lining wear. Because the determination of the amount of particles formed from the wear of brake linings depends on various parameters other than the sampling location. The most important reason for this is the lack of standardized sampling procedures and measurement techniques. This is often investigated by researchers based on various experimental approaches. Therefore, it leads to incomparable results and conclusions.

The chemical composition and level of harmfulness of the particles formed as a result of the wearing of the brake linings of specialized vehicles largely depends on the driving of the car, in particular, the braking efficiency and the coefficient of wheel traction. Speed, condition and maintenance frequency of specialized vehicles are also important parameters. The conditions under which the braking event occurs (temperature and environmental chemicals) greatly affect the properties of the resulting particles.

2 Materials and Methods

Despite the difficulties in measuring and characterizing the amount of particles formed as a result of the wear of brake linings of specialized vehicles, the number of studies conducted in this regard is increasing. The analysis of the literature shows that considerable scientific work is being carried out on the quantity, physical-chemical properties, degree of harm and negative effects on human health of the particles formed as a result of the wear of brake linings. Also, this research aims to identify the main shortcomings of the above-mentioned problems, to determine the amount of particles, taking into account the adhesion coefficient of the wheel with the road.

Two types of brake mechanisms are widely used in modern vehicles: - In the disc brake mechanism - the disc rotates and two fixed pads are installed inside the caliper. The working cylinders are mounted on the caliper, and during braking, they compress the brake pads against the disc. - In the drum brake mechanism - it is installed on the rear wheels of a passenger car. During operation, the gap between the tires and the drum increases, and mechanical regulators are used to eliminate it. A graphic representation of the disc brake mechanism is presented in Fig. 1.
Modern cars are usually equipped with a front disc and rear drum brake mechanism. It is estimated that the front brake mechanism must provide about 70% of the total braking power and therefore needs to be replaced more often than the rear brakes. The car brake mechanism mainly consists of friction pairs consisting of disc, pads and brake lining. Discs used in the brake mechanism of specialized vehicles are usually made of gray cast iron, but in some cases they are made of chemical elements such as reinforced carbon, ceramic composites and aluminum.

A brake disc usually mainly contains binders, fibers, metals, anti-friction additives and lubricants: [2, 3]. Binders hold brake disc components together and provide structural integrity of the lining under mechanical action. Binders make up 20-40 percent of the coating material and are made from modified phenol-formaldehyde resins. Reinforcing fibers provide mechanical strength and structure of metals. Reinforcing fibers usually make up 6-35 percent of the coating material by mass. Reinforcing fibers can be classified as metallic, mineral, ceramic or organic. Base materials are used to improve heat and noise absorption properties, as well as to reduce production costs. The basic substances usually consist of inorganic compounds (barium and sulfate, magnesium and chromium oxides), silicates, crushed slag, stone and metal powders. It makes up 15-70 percent of the coating material by mass. Oils affect the friction and wear properties of the mechanism. Usually, graphite plastic lubricants are used. Oil caustics are used to increase friction, maintain cleanliness between contact surfaces, and limit the buildup of conductive films [3].

There are generally three types of brake linings available on specialty vehicles: non-asbestos organic (NAO), semi-metallic, and low-metallic. NAO type pads are relatively soft and exhibit lower brake noise compared to other types of pads, but they lose braking ability at high temperatures and generate more dust than other types [4]. For many years, brake pads were made from asbestos fibers, but due to their serious harmful effects on human health, now asbestos-free pads have been manufactured. A low-metallic, 07012 (2024)
A metal block consists of organic substances mixed with a small amount of metals (10\%-30\% by mass). They exhibit friction and good braking ability at high temperatures. Semi-metallic brake pads have a high metal content (up to 65\% by mass), which makes them more durable and provide excellent heat transfer. On the other hand, these discs tend to wear out faster and exhibit high noise characteristics. For high performance requirements or extreme braking conditions (sports cars, ambulances, police cars), metal coatings containing steel and copper fibers are used [2, 4].

The chemical composition of brake pad material is given in Table 1.

<table>
<thead>
<tr>
<th>Raw material name</th>
<th>Density (kg/m^3)</th>
<th>Volume %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bonding silicon carbide</td>
<td>3.21</td>
<td>15</td>
</tr>
<tr>
<td>Filler barium (BaSO_4)</td>
<td>4.5</td>
<td>12</td>
</tr>
<tr>
<td>Synthetic graphite</td>
<td>2.32</td>
<td>8</td>
</tr>
<tr>
<td>Aluminum (Al_2O_3)</td>
<td>3.95</td>
<td>11</td>
</tr>
<tr>
<td>Zinc</td>
<td>7.14</td>
<td>9</td>
</tr>
<tr>
<td>C, ( \text{C}_{0.506} )</td>
<td>1.506</td>
<td>8</td>
</tr>
<tr>
<td>Copper</td>
<td>5.7</td>
<td>19</td>
</tr>
<tr>
<td>Iron</td>
<td>7.874</td>
<td>18</td>
</tr>
</tbody>
</table>

The friction between the disc and the pad creates particles of different sizes. During a braking event, a mechanical effect is exerted on the pad, which moves against the disc and converts the car's kinetic energy into thermal energy. In addition to mechanical friction, car brakes generate high heat. The surface friction between the disk and the pad creates mostly micron-sized particles. Figure 2 shows different size images of solid particles produced as a result of brake mechanism tests carried out under laboratory conditions.

\[ \text{Fig. 2. SEM images of brake linings wear particles [1]} \]
Some disc brake systems require low-pressure pad-to-disc contact to ensure solid braking. This leads to excessive release of particles in the environment. A detailed explanatory model of the complex contact between the brake pads and the cast iron disk was developed by researchers [6, 7]. In this model, the movement of macroscopic friction and solid particles of the brake disc can be explained by the state of microscopic contact (growth and destruction of contact plateaus) in the boundary layer between the pad and the disc [3]. The brake disc moves from left to right on the pad surface. The flow of worn particles in the gap between the pad and the disc is shown [8]. Figure 3 shows a simplified visual representation of the model.

![Fig. 3. An image of the contact state between the mount and the disc [1]](image-url)
through an open sampling system [12]. The size distribution of the particles formed as a result of the corrosion of brake linings is of great importance. Because most of the formed particles are small in size.

By M. Riediker in 2008, when testing the front brake linings of six different passenger cars under environmental conditions (compared to rear brakes), it was found that the particles formed change to small sizes and that a full stop of the car produces higher particles compared to normal deceleration [11].

The chemical composition of the particles formed as a result of the wear of brake linings should be taken into account in their full description and assessment of their negative impact on human health. Heavy metals in the particles formed as a result of the brake linings wear have a negative effect on human health.

Modern brake mechanisms are composites of many different and sometimes unknown components. The chemical composition of the particles formed as a result of the wear of brake mechanism details is significantly different from the chemical composition of the original coating material. In order to fully consider how the braking process affects the chemical composition of the corrosion particles of brake mechanism parts, it is necessary to consider the materials used in the parts and the composition of the worn particles. The chemical composition of the materials used in the production of brake linings mainly uses metals such as Fe, Cu, Zn and Pb. The percentage of Fe (iron) in brake mechanism parts can reach up to 60 percent, which varies depending on the type of coating [9]. The amount of K, Ti, and Pb in brake linings is 12 percent by weight. In modern coatings, other metals such as Ba, Mg, Mn, Ni, Sn, Cd, Cr, Ti, K and Sb also make up to 0.1 percent by weight [13].

Table 2 shows the elemental composition of the particles formed during the braking process.

<table>
<thead>
<tr>
<th>Table-2. Metal particles formed during braking [10]</th>
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<tbody>
<tr>
<td>Metall</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>Al</td>
</tr>
<tr>
<td>Mn</td>
</tr>
<tr>
<td>Ba</td>
</tr>
<tr>
<td>Ca</td>
</tr>
<tr>
<td>Co</td>
</tr>
<tr>
<td>Cr</td>
</tr>
<tr>
<td>Cu</td>
</tr>
<tr>
<td>Fe</td>
</tr>
<tr>
<td>K</td>
</tr>
</tbody>
</table>
Nowadays, particles formed as a result of wearing of brake linings have a high content of Sb. This element is used in the production of brake linings in the amount of 1–5 percent Sb (Sb_2S_3) in the form of stibnite. Sb is used as a lubricant to reduce vibrations and improve frictional stability. As a result of the tests carried out in different geographical regions (Europe and Japan), samples containing Sb and S in the composition of brake linings were determined. Stibnite is converted to Sb_2O_3 during braking. It is classified as a carcinogen [14].

Brake pads contain the most types of phenolic compounds. Also, the particles formed as a result of braking on the road surface contain carbonyl compounds, organic acids and aromatic carboxylic acids.

The chemical properties of the base coating material are often changed by the high temperature and pressure generated during the braking process [11]. It is characterized by a specific pattern of some heavy metals (Fe, Cu, Zn, Sn, Sb), which are similar to the coating material. These elements are contained in particles formed during braking. As a result of studying the composition of particles formed as a result of braking, it was found that very small particles mainly consist of Fe, Cu, Ti, Al. Particles appear mainly in the form of Fe oxides. This means that brake linings are the particles released into the environment as a result of wear [11].

Particulate graphite is formed by abrasive solid particles. Similarly, in "normal deceleration" and "full stop" forms of braking, high concentrations of Fe and Cu are formed. Fe, Cu, and Mn are highly correlated, and their common brake deposits originate from particles formed by wearing. Fe, Cu, Ti, S, and Zr elements make up 72% of the particles formed as a result of the corrosion of brake linings [51].

Polyalkylene glycol ethers (56.9%) and n-alkanoic acids (34.3%) are the most abundant types of n-alkanes, polycystic aromatic hydrocarbons (PAH) among the organic compounds detected in the particles formed as a result of the wear of brake linings [8].

It is advisable to study the amount of particles released into the environment as a result of the wear of brake linings by the regulatory agencies as a specific pollutant by individual vehicles or car fleets. It is a functional relationship that predicts the amount of pollutant particles produced as a result of vehicle movement, the amount of energy or fuel consumed. The amount of particles produced by the wear of brake linings is usually obtained for vehicle categories. These depend on several parameters, the most important of which are vehicle characteristics and emission control technologies, type and quality of fuel used, environment and operating conditions [8]. The amount of particles produced by wear of brake linings was determined by measuring the amount of particles, including under real test conditions or laboratory experiments or mathematical modeling.

In a 2010 study of NAO brake pads by K. Giethl, R. Lawrence, A. J. Thorpe, and RM Harrison, it was determined that brake pad wear rates ranged from 0.039 to 0.058 g/km. In general, it was determined from direct measurements that the particles produced by the wear of brake linings as a result of the movement of light trucks range from 0.03–0.08 g/km to 0.21–0.55 g/km [14].
Particles formed as a result of wearing of brake linings around intersections on city highways contain a large amount of heavy metals. On highways and tunnels, the particles formed as a result of brake lining wear are found in small quantities. Also, in tunnel research, it was found that the amount of particles formed during braking for light trucks is 0.01 g/km. The National Air Emissions Inventory (NAEI) has provided a total number of harmful particles for each type of vehicle in the UK fleet by combining the particulates produced by driving mode and start-up. They found that the wear rate of passenger car brake linings was 0.7 g/km. It has been proven that 40% of the particles formed as a result of braking become part of the atmosphere [15].

In 2000 research conducted by B.D. Garg, it was determined that the particles formed by braking contain metal elements S, Ti, Fe, Cu and Zr, and the rate of wear of brake linings is in the range of 0.014-0.037 g/km [9]. B. D. Bukovieski conducted research in 2009 and it was found that the particles formed as a result of brake pad wear on local highways were contaminated with elements of Fe, Cu, Zn, Mo, Zr, Sn, Sb and Ba [16, 17, 18, 19, 20].

3 Analysis of research results

The inspected section of Islam Karimov Avenue is straight, the coefficient of wheel contact with the road is 0.5-0.6, the slope is 3% on the dry surface, and the width of 15 m is equipped with asphalt pavement and curbs. Before sampling, there was no precipitation for 4 days and the temperature at the time of sampling was between 19 and 24°C. Islam Karimov Avenue measured average vehicle speed of 50±5 km/h (cars), 50±3 km/h (trucks) and 60±4 km/h (buses). The average speed of a car in the center of Jizzakh city is 50±6 km/h for one type of car, the average speed of a car measured on the pavement of the 74-75 kilometer section of the 4r32 "Yangiyer-Pakhtakor-Chimkurgan" highway is about 70±9 km/h, and the adhesion coefficient of cars wheels with the road was 0.5 ÷ 0.6. 4r32 "Yangiyer-Pakhtakor-Chimkurgan" highway, the average value of the adhesion coefficient of the 76-77 kilometer section of the road surface was 0.7 ÷ 0.8.

The test work was carried out from 12-00 to 14-00 in dry, cloudless air at an ambient temperature of +21-+28 °C (April-May 2020 and September-October 2022). The size, composition, and quantity of particles formed as a result of wear of brake linings and tires were determined using the X-ray diffractometer Empyrean (PANalytical) available at the Advanced Technologies Center. Particles produced during braking were determined on the road surface of Islam Karimov Avenue, 74-75 kilometers of the 4r32 "Yangiyer-Pakhtakor-Chimkurgon" highway and 76-77 kilometers of the 4r32 "Yangiyer-Pakhtakor-Chimkurgon" highway in Jizzakh region.

Figure 4 shows the microscopic view of the samples taken on the surface of the road surface as a result of the test results to determine the elemental composition of the particles formed on the surface of the road surface during the braking of cars on the road surface of Islam Karimov Avenue.
Fig. 4. Microscopic view of the samples taken from the particles produced by the braking of cars on the pavement of Islam Karimov Street.

Fig. 5. Elemental analysis of the samples taken from the particles produced by the braking of cars on Islam Karimov Avenue.
"Yangiyer-Pakhtakor-Chimkurgon" highway 74-75 kilometers of the highway, as a result of the test results to determine the element composition of the particles formed on the surface of the road surface as a result of the braking of cars, the microscopic view of the samples taken from the surface of the road surface is presented in Fig. 6.

**Fig. 6.** Microscopic view of the samples taken from the particles produced by the braking of cars in the distance of 74-75 kilometers of the highway "Yangiyer-Pakhtakor-Chimkurgon"

"Yangiyer-Pakhtakor-Chimkurgon" highway 74-75 kilometers, the analysis of the samples taken from the particles resulting from the braking of cars by the composition of elements is presented in Fig. 7.

**Fig. 7.** Analysis of samples taken from the particles produced by braking of cars in the 74-75 kilometer section of the "Yangiyer-Pakhtakor-Chimkurgon" highway according to the composition of elements
Fig. 8. Microscopic view of the samples taken from the particles produced by the braking of cars in the distance of 76-77 kilometers of the highway "Yangiyer-Pakhtakor-Chimkurgan"

Fig. 9. Analysis of the samples taken from the particles produced by the braking of cars in the 76-77 kilometer section of the highway "Yangiyer-Pakhtakor-Chimkurgan" according to the composition of elements
follows. I.Karimov avenue (φ=0.5÷0.6) was found to be contaminated with 0.047 g/km, 74-75 kilometers of highway 4r32 “Yangiyer-Pakhtakor-Chimkurgon” (φ=0.5÷0.6) - 0.025 g/km and 4r32 “Yangiyer-Pakhtakor-Chimkurgon” road surface between 76-77 kilometers (φ=0.7÷0.8) was 0.015 g/km.

4 Conclusions

All over the world, research is being actively conducted to reduce transportation costs, environmental impact, and efficient use of tires in automobile transport. The results of republican and foreign research on determining the amount of harmful particles emitted from brake linings and tire wear as a result of vehicle movement are presented. In short, the relatively high content of Fe, Cu, Sb in the particles formed as a result of wearing of brake linings indicates that the rate of wearing of passenger car brake linings is 0.011-0.51 g/km.

References


16. Ismayilov K., Alimova Z., Asqarov I., Karimova K. “The Research On Road Dust And Particles Caused By Traffic (on the example Jizzakh city)” Problems in the textile and 07012 (2024)E3S Web of Conferences https://doi.org/10.1051/e3sconf/202450807012

