48. mezinárodní konference kateder dopravních, manipulačních, stavebních a zemědělských strojů

září 14.- 16., 2022 – osada Jizerka, Česká republika
Technická univerzita v Liberci
Fakulta strojní, Katedra vozidel a motorů

PRACTICAL ASSESSMENT OF THE FRICTION MATERIAL WEAR IN DISC BRAKE PADS OF HEAVY-DUTY VEHICLES OPERATING IN EUROPE AND ITS ENVIRONMENTAL IMPACT

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Abstract
The article focuses on practical assessment of disc brake pads in semi-trailer trucks operating on European roads. Data processing is carried out according to the practical data of a transport enterprise from Bulgaria. The presented results are on the amount of produced friction material per millimeter of worn-out brake pad friction layer and per km mileage of the pad. Additionally, the factors affecting the wear of the friction pair "brake disc-brake pad" are described and a simplified expert assessment and ranking

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of these factors is carried out. The impact on the environment and the human health by the friction material wear and its production of PM is considered.

1. INTRODUCTION

Non-exhaust (airborne) particulate matter PM10 and PM2.5 (with references to their sizes – smaller than 10 and 2.5 microns in diameter respectively), account to almost a halve of the overall PM emissions in Europe. [1] Mostly generated from braking elements and tyres in vehicles, as well as the road decomposition, non-exhaust PM are significantly hazardous not only for the human health, but also for the well-being of other species and the soil. The European Commission has adopted a plan for transitioning to zero on-board emissions for a large amount of the future vehicle fleet [2], yet there is no concrete plan for the dealing with the emissions of airborne PM, which gradually grow with the increase of the vehicle fleet in use and amount to as much as 30mg/km, depending on the vehicle type (light-duty, heavy-duty), the road type (urban, rural, highway) and many other factors.

Many laboratory studies have analysed the chemical composition of friction layers on brake pads in regards to the PM, in order to create a methodology for lowering of their emittance [3-7]. Most of them, however, have revealed that inclusion of metallic elements in the friction material affects beneficially the performing properties of the braking element. Simultaneously, these same metallic elements (Cu, Fe, Zn, Ca, Pb, Al, oxides and others) act for the most serious threat to human health and the environment when considering airborne PM. Moreover, many factors affect the generation rates and the physicochemical nature of these particles in real conditions, making it very hard to study them affectively. Even though many sampling methodologies with different speeds and accelerations have been proposed, the results are hardly comparable.

The different means of transport and more particularly the different types of vehicles in road transport account for a different amount of airborne PM generated. Although heavy-duty vehicles represent a smaller part of the European vehicle fleet in use, it is very important to study their regard to the topic as well, as the statistics show they have a significantly higher emission factor than light-duty vehicles [8]. This is mainly due to the abundance of additional factors, influencing the intensity and the amount of braking during the operation of such vehicles. Very little practical research has been conducted in regards of the actual PM generation from braking elements of high-duty vehicles operating in Europe, as most of the studies focus on chemical compositions of the braking material, or on emittance of PM by usage of laboratory samplings from testing on brake dynamometers or light-duty vehicles.

Furthermore, analysis that are based on practical statistical data of two Ukrainian transport enterprises – LAA TRANS and TRANSPELE taken for the period 1999-2005 on all kinds of routes around Europe, show that the truck brake system is most likely to malfunction or failure averagely every 188 thousand km. [9] This malfunction or failure could be due to various technical reasons, one of which is the clogging of the brake mechanism resulting from the excessive amount of road dirt, moisture and friction material dust, generated by the friction pair “brake disc-brake pad” during the process of braking. During the operation of the high-duty vehicle, the technical condition of the brake system significantly affects not only the environmental safety, but also the operational properties and the road safety of the vehicle. A failure of the elements in the brake system during operation can cause dangerous consequences:

lower road safety, decrease of functionality, low operational quality and others. According to [10] for example, there is a very strong positive correlation between failure of the vehicle braking system and the road accident rate.
Considering everything mentioned above the paper focuses on a practical evaluation of the missing brake material on standard disc brake pads that are measured during different stages of their exploitation and were used on trucks, trailers and semi-trailers, operation in Europe. Additionally, a simplified expert assessment of the factors influencing the brake pad wear and innovative solutions for collection of the resultant PM are presented.

2. PRACTICAL ASSESSMENT OF THE DISC BRAKE PAD WEAR AMOUNT

The value of brake pad wear for the truck, trailer and semi-trailer vehicle fleet of the enterprise "EMG TRANS" (Bulgaria) was estimated. The main route of the vehicles started from Bulgaria (the fleet operated on various roads with all types of profiles) through Romania (mainly Calafat-Turnu Severin-Timisoara-Arad-Nadlak or Calafat-Turnu Severin-Timisoara-Arad-Oradea), and through Hungary (Nagylak-Szeged-Budapest-Gyor-Rajka or Nagylak-Szeged-Budapest-Sahy, or Artand-Debrecen-Miskolc-Sena) and finished in Slovakia or Czech Republic (again circulating in the country on various roads with all types of profiles) with different nuances in terms of mileage depending on the places of loading or unloading of goods (see figure 2). The route was travelled in both directions. The workload of the vehicles varied, but was always within 25-38 tons total weight for the whole truck tractor – semi-trailer or truck – trailer composition.
The data was gathered in 2018-2019 from brake pads that were removed from service during different stages of their period of exploitation, but mostly at its end. According to the scheduled and unscheduled replacements of disc brake pads of the enterprise's vehicle fleet for the period 2018-2019, most frequently the change occurs at about 150 - 200 thousand km mileage of the pads.
It is important to mention there are few cases in which all two pads on a certain wheel or all four pads on a certain axle are changed prematurely during a scheduled preventive vehicle technical inspection, without reaching their maximal average mileage count. This change is caused by the necessity of having approximately evenly worn-out pads for both sides of each axle for the axle alone. Such approximate evenness guarantees better braking functionality and quality, as well as better vehicle controllability and a lower chance for a loss of controllability during the process of braking.
Another case in which pads are prematurely changed is when their residual resource at the time of the scheduled technical inspection does not financially justify their eventual future change, which would occur unscheduled during a period that is normally used for exploitation of the vehicle.
In parallel, when the operating conditions are very favourable, pads could reach their maximal resource after up to 600 thousand km. It has also been observed that such infrequent changes are more common when a new semi-trailers or truck is in service for the first time, as well as when vehicles transport light-weighted cargos on highways with easy road profiles, or when the vehicles is supplied with an additional brake system (retarder/intarder).

It should be taken into account that the recommended minimum residual thickness of the pad friction material is 5 mm, hence at 5mm thickness of the friction material left, the pad is considered to be 100% used. Therefore, the theoretical operation period of a brake pad with a standard thickness of 30 mm (the metal part is 9,5 mm thick) ends at friction material wear of 15,5 mm.

Figure 1: *Operational route of the vehicle fleet of EMG TRANS*

The measuring of each sample brake pad was done by estimating with a calliper the existing friction material amount and also by measuring the weight of the pad with an electronic scale. The weight and thickness of the used friction material were then calculated by subtracting the measured values from the standard values of a new pad. The measured braked pads are of two sizes – for discs with diameter φ370mm, used in trailers, and for discs with diameter φ430mm, used in trucks and semi-trailers. The pads are produced from a few different companies, which all use different chemical compositions of the friction material and a slightly different geometry of their pads, the pads could easily be distinguished by their form, weight and wear properties, which is also visible from the results. Nevertheless, a standard new brake pad has a thickness of 30mm, 20.5 of which - friction material thickness.
On figures 2 and 3 is shown the measured data of 10 brake pads used for φ370mm discs in trailers and of 10 pads with φ430mm used in trucks and semi-trailers. The figures represent missing friction material in grams per missing friction material layer worn-out from the pad in milometers. At the left bottom corner of each graph is positioned a point representing an unused new pad with 0mm missing friction layer thickness and 0g missing friction material mass. Additionally, in each of the figures are shown images of a new and a used brake pad for each of the discs. A trendline is

projected in order to show the average tendency g/mm of friction material wear. The bubble indicates the highest density in terms of measured braking pads, showing that most of them were measured at the theoretical end of their operational period.

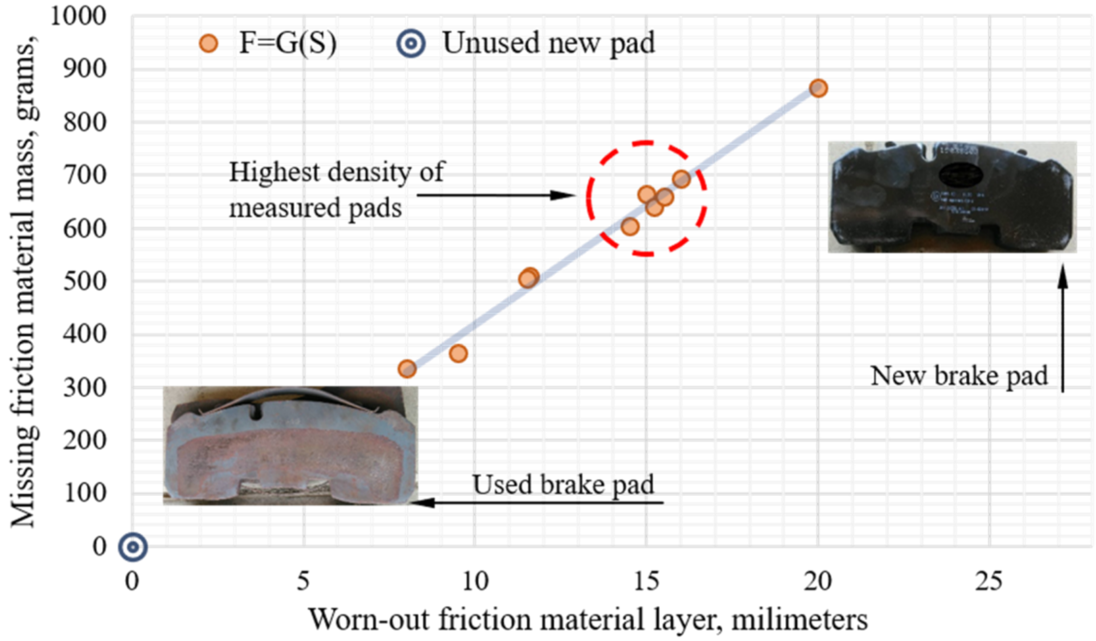


Figure 2: Missing friction material mass to worn-out friction material layer, g/mm for φ370mm disc.

The results show that brake pads of φ370mm discs produce about 38.42-44.34 g of particles per each mm of friction material used, while the larger brake pads with φ430mm discs produce 74.14-96.67 g of particles per each mm of friction material.

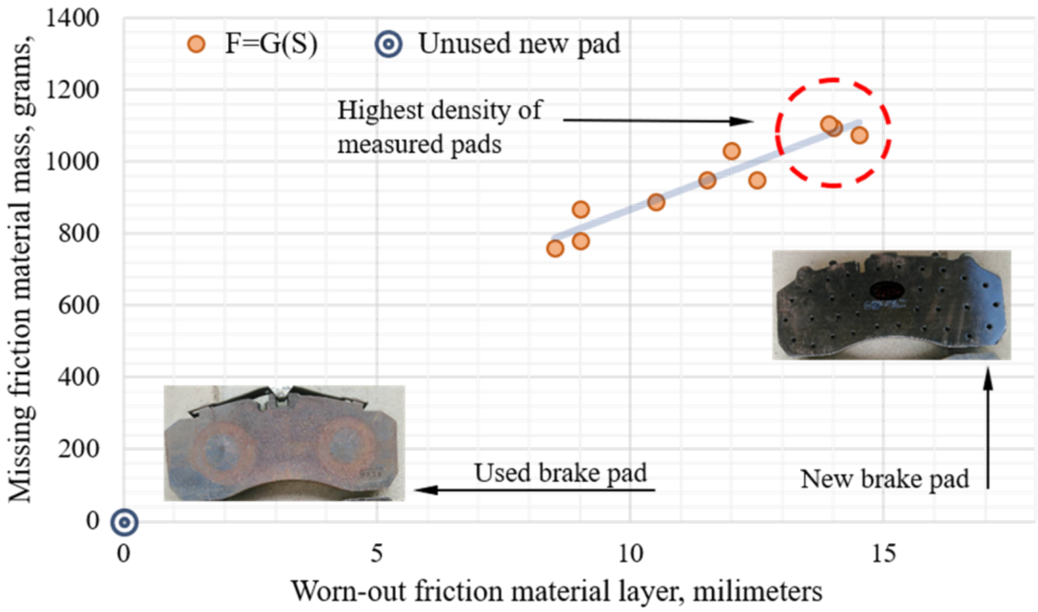


Figure 3: Missing friction material mass to worn-out friction material layer, g/mm for φ430mm disc.

The values of brake pads wear in g/mm could easily be calculated in mg/km. However, it is very important to properly set the average mileage of the pads as it depends on many factors, such as the route of the vehicle fleet, the average gross mass of the goods transported, and many others. According to the statistical data of the enterprise which supplied us with pads, the average pad mileage of their fleet is about 150-200 thousand km. In this case, the pads generate about 3.37-3.90 mg/km of PM for the φ370mm discs, while the values of the larger brake pads correspond to 6.56- 8.56 mg of particles per km.

Such wide ranges of g/mm are due to the different chemical composition of the friction material on the pad, since the pads are produced by various companies.

2.1 Expert evaluation of factors influencing wear of friction material on brake pads.

The amount and evenness of brake pad wear depends on many factors. To evaluate them, an expert assessment was carried out in which experts and workers from University of Zilina (Slovakia), ŽOS (Slovakia), the Zhytomyr Polytechnic State University (Ukraine) and a transport enterprise from Bulgaria took part.

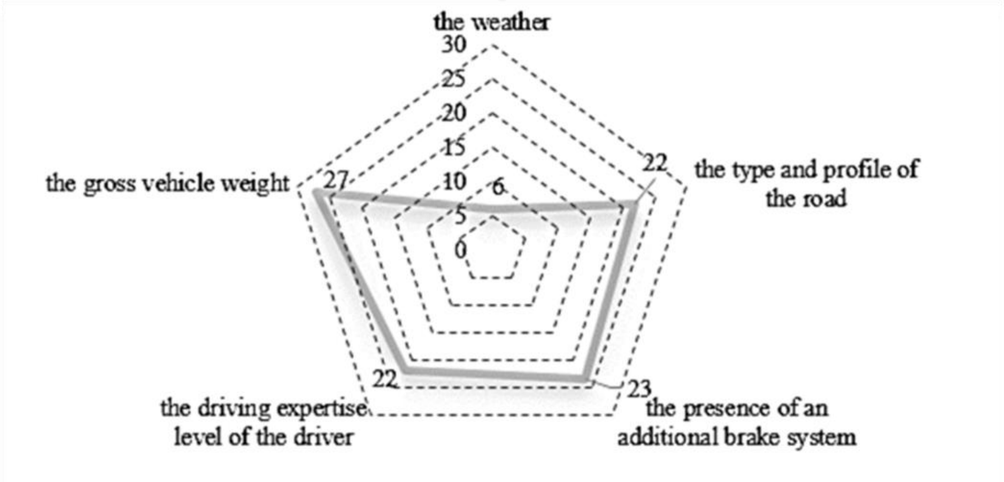
The experts were asked to rate in a questionnaire the main factors affecting the amount of disc brake pad wear in order in %, as the 5 factor options were given. The sum of all factor ratings is 100%. The factor options are:

- gross vehicle weight;
- the expertise level of the driver;
- road type (urban, rural, highway) and road profile;
- the presence of an additional brake system – retarder/intarder;
- weather.

As a result of processing the data, a diagram was obtained (see figure 4), according to which the brake pad wear depends most significantly on the gross vehicle weight, while the weather is rated as the least significant factor.

Figure 4. Main factors' influence on brake pad wear in %.

The additional brake system – retarder/intarder lowers the brake pad wear at expense of its high cost and additional energy usage. Nevertheless, this topic is not part of our study.



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It is very important to note that there are many other factors that rarely are being taken into account, yet sometimes they heavily influence the quality and amount of braking, as well as the production of PM:

- the distribution and types of goods as well as their possible relocation in the trailer/semi-trailer when braking;
- the technical specification of the whole heavy-duty vehicle, most notably the wheelbase;
- the level of emergency of the delivery;
- the presence of overloading and its amount;
- the running-in time of new pads;
- others.

The operation time of a braking pad (the mileage it could run) and therefore the amount of PM it would emit depends on all the above-mentioned factors.

2.2 On-board vehicle solutions for lowering of the amount of PM from brake pad wear

As elaborated above, the wear of the brake pads and thus the production of PM is directly or indirectly affected by a number of factors. In order to somewhat eliminate the problem of pollution from PM and also lower the significance of their generation process, various active and passive solutions for decreasing of the amount of PM, have been developed.
Typical passive solutions are the electric and hybrid drives, retarders, intarders and motor brakes. They help in facilitation of the work of the main brake system and so reduce the amount of formed solid particles to the lowest possible level. Hybrid and electric drives allow for regenerative braking, while retarders, intarders and motor brakes aid the braking process by means of fluid circulation. Active solutions, on the other hand, are focused on the direct capture of PM which is normally released during braking into the atmosphere. They are not commonly used yet, but there are several prototypes being developed by some automotive suppliers.

Figure 5: *Prototype of a vacuum cleaner installed on the brake disc for collection of PM.*

The French manufacturer “Tallano Technologies” has designed a vacuum cleaner which sucks out the dust produced from the brakes (see figure 5) [11]. The PM are captured in a filter installed in the vacuum cleaner. This device can be fixed directly on the discs of an existing car. According to the company creator, the device evacuates 65 to 80 % of the total amount of PM produced by the brakes. The device is currently undergoing final tests on a car in Paris.
The German manufacturer of filters “Mann + Hummel” has designed a filter which is installed as a continuation to the brake calliper (see figure 6). It is possible to be fitted on any of the existing brake discs and is adaptable to different brake sizes and concepts [12].

Figure 5: *Prototype of a filter installed as a continuation of the brake calliper for collection of PM.*

3. CONCLUSION

The impact of PM emitted by vehicles on the environment, on the technical condition of vehicles as well as on the health of the population living near roads is considerable. Many studies have shown that not only internal combustion engines produce PM, but that in certain conditions much higher amounts are actually emitted by the brake pads friction materials. There are many factors affecting the amount of PM from brake pads, especially in the case of heavy-duty vehicles. According to the assessment in the study, the gross vehicle weight plays the biggest role in PM generation from braking in heavy-duty vehicles. The results estimated from vehicles operating on standard routes in Europe with an abundance of different road types and road profiles, that on average 3.37-3.90 mg/km of PM from braked pads with brake disc diameter φ370mm and 6.56-

8.56 mg/km with brake disc diameter φ430mm, is produced. These values are significantly lower than the publicly presented data of up 30 mg / km and show how significant is the influence of the already mention factors on production of PM from disc brake pads.

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ACKNOWLEDGEMENT

The paper was supported by the Scientific Grant Agency of the Ministry of Education of the Slovak Republic and the Slovak Academy of Sciences in project KEGA, no.

KEGA 023ŽU-4/2020: Development of advanced virtual models for studying and investigation of transport means operation characteristics.
“This publication was realized with support of Operational Program Integrated Infrastructure 2014 – 2020 of the project: Innovative Solutions for Propulsion, Power and Safety Components of Transport Vehicles, code ITMS 313011V334, co-financed by the European Regional Development Fund”.