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Research Article

Analysis of PM Dimensions in Disc Pad Interaction in Commercial Vehicles

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Abstract **–** Nowadays, the brake system plays an essential role in commercial vehicles, and brake systems are created with different working principles and designs. While mechanical, hydraulic, and hydraulic pneumatic brake systems were used at the beginning, pneumatic brake systems have started to be widely used due to technological developments. The need for braking, especially in situations such as downhill descent, has also created additional brake systems. In addition to safe and optimum braking, these systems aim to provide a longer life for the brake pads, which are essential parts of the brake system, and wear out in a shorter time than the disc or drum. For many years, various standards have been established for vehicle emission standards, and these standards have been reorganized according to the day's conditions. The basis of vehicle standards is the reduction of emissions from combustion in internal combustion engines. In addition to reducing emission rates from internal combustion engines in international standards, there are efforts to standardize the amount of particulate matter from other systems, such as vehicle tires or brake systems. These standards are also crucial for electric vehicles rapidly replacing internal combustion engines. In this study, a sample taken from the brake lining of a load-carrying commercial vehicle was subjected to an abrasion test in a pin-on type device, and the resulting PM mass number quantities and average particulate matter sizes were determined.

Keywords – Braking System, Vehicle Technologies, Disc, Brake Pad, Particulate Matter

I. INTRODUCTION

People use different means of transportation while living their lives. The movement provided by internal combustion engines burning different fuels in vehicles is transmitted to the wheels as kinetic energy through the drivetrain as desired by the driver. With the braking request, the brake system converts this kinetic energy into heat energy. The active safety system provides the desired performance in braking based on the interaction between the disc drum, part of the brake system, and the brake pad [1], [2].

Dozens of different materials are used in the content of brake pads, which are an essential element of the system in brakes. The most important features required from brake pads are good braking performance, stable friction coefficient, high wear resistance, and environmental friendliness [3]. In most studies on environmental harmlessness, researchers and industrial companies have focused on eliminating asbestos used in the brake lining content [4]. In most of the studies, substitute materials that can be used instead of asbestos have been identified, and these materials, which are not considered harmful to the environment, have been used in brake lining contents. The materials used in the lining content instead of asbestos consist of different products such as organic or mineral-based products.

For the developed brake pads to provide the desired performance, brake pads should be produced by using correctly selected materials with different properties together [5]. Many different materials are used together to create brake pads. The many complex requirements and properties of brake pads are mainly achieved through binders, friction modifiers, reinforcements, and fillers. The selection and optimization of functional additives and the creation of suitable recipes play an important role in performance criteria [6].

The materials used to create brake pads must be environmentally benign and advantageous in cost and performance. The depletion of some resources with the advancement of technology has led to an increase in the search for alternative materials [7]. Vehicles' stopping or slowing down is ensured by the friction of the pads consisting of more than one material in the brake systems against the disc [8]. Vehicle braking can be push-pull or continuous, such as on a downhill slope. Some drivers may also brake suddenly while continuing to press the accelerator pedal because they cannot adjust the speed correctly. This has a particularly negative impact on fuel consumption [9]. Besides fuel consumption, dust particles are emitted into the atmosphere with the wear caused by friction during braking.

The new Euro 7 standards for road transportation aim to protect human and environmental health by providing cleaner and better air quality for vehicles, which are the primary source of air pollution in cities. The Euro 7 vehicles and CO_2 emission standards have been established to determine air quality. With the additional proposal to these standards, in addition to the pollutants from the exhaust of internal combustion engines, emissions from brakes and tires are also addressed [10]. Due to environmental awareness and additional emission standards, the size of particulate matter resulting from wear in brake pads is essential.

Braking performance is taken into account in most of the studies on brake pads. This study took samples from a commercially available brake pad of a load-carrying vehicle. The samples were subjected to abrasion tests at different loads in pin ten type abrasion testers, and the mass and number of particulate matter masses and average particulate matter sizes during abrasion were determined.

II. MATERIALS AND METHOD

Lining samples with a diameter of 25 mm and a height of approximately 12-13 mm were taken from the standard disc-type brake pad of a heavy load-carrying commercial vehicle shown in Figure 1. The surface of the lining samples was smoothed with sandpaper.

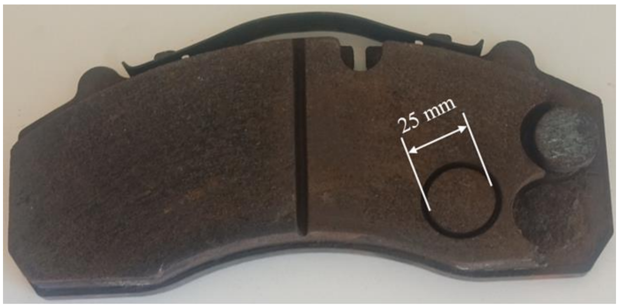

Fig. 1 Commercial vehicle disc brake pad and sampling images

The lining specimen was placed in the pin-on type specimen holder and acclimatized to the disk for 1 hour. Afterward, the specimens were subjected to wear tests under different loads and constant speed conditions specified in Table 1. The pin-on type device used during the experiments was isolated from the external environment with a cover to prevent contact with the external environment during measurements. Clean air filtered by a fan was circulated to the experimental environment during the experiment. A laser-type PM sensor was used to detect PM in the worn pad. The computer program recorded instantaneous data from the sensor, and graphs were created with these data.

Table 1. Pin on disk wear test experimental conditions

Criteria	Operating characteristics
Disk rotation speed (m/s)	6 (Constant speed)
Fan speed (m/s)	3.6
Sample center average friction diameter (mm)	185
Load applied to the brake pad (N)	20-30-40-50 (Variable load)
Experiment duration (min)	30

III. RESULTS AND DISCUSSION

Table 2 shows the average PM mass concentrations and PM percentages. The study conducted in the literature on the subject [11] shows that the mass concentration is 80000-120000 µg/m^3 although it varies according to the samples produced. Compared with the commercial lining used in this study, the mass concentration values were lower than the results measured in the literature. The low measurement results are noteworthy regarding reducing particulate matter emitted into the environment.

Table 2. PM mass densities and PM percentages at different loads

Load (N)	PM Type 1.0**	2.5**	4.0**	10**
20	20324.16	35704.29	47267.14	53061.22
	13.00*	22.84*	30.23*	33.94*
30	20955.16	32872.86	42870.42	47880.13
	14.49*	22.74*	29.65*	33.12*
40	19010.47	31415.5	40619.28	45231.24
	13.95*	23.05*	29.81*	33.19*
50	18754.46	30437.98	39066.72	43390.53
	14.25*	23.12*	29.67*	32.96*

*Percentage rate, ** µg/m^3

The instantaneous PM mass densities obtained from the experiments are shown in Figure 2. The maximum mass density was PM10 at all load conditions, and the order was PM4.0, PM2.5, PM 1.0. In the first stages of the test, the values were slightly high due to the effect of the disk getting used to the lining. At this stage, which is the first stage, it was determined that the amount of particulate matter emerging due to wear on the lining was high.

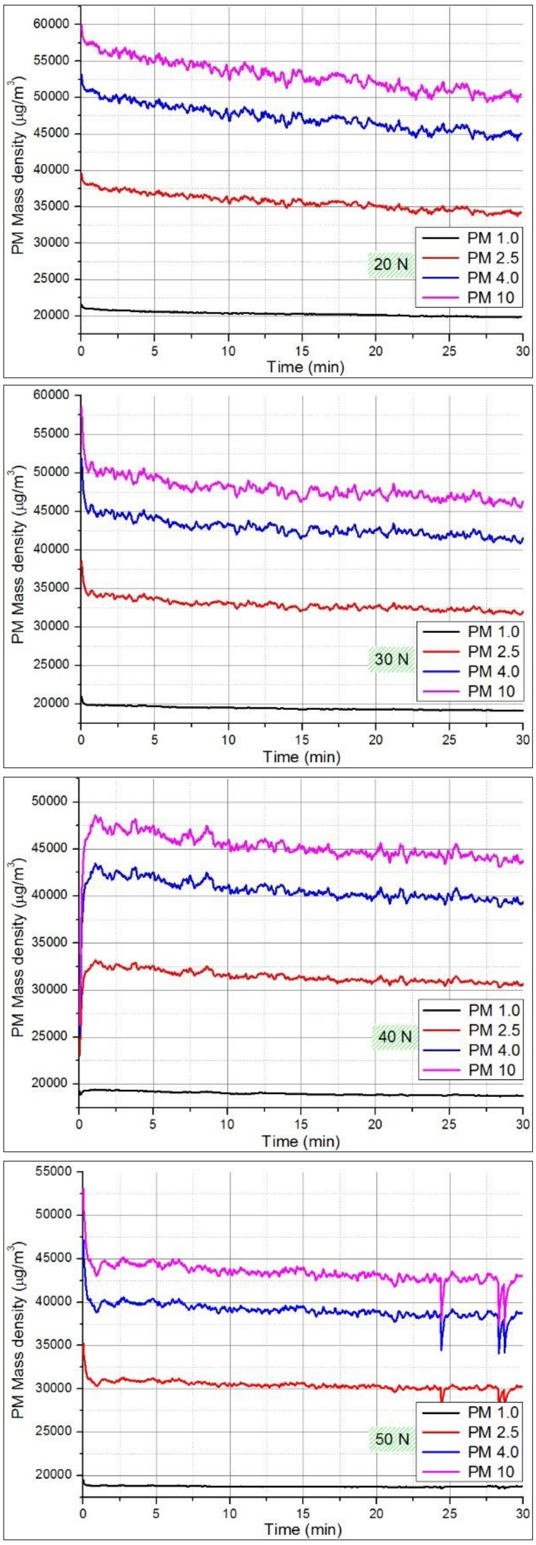

Fig. 2 PM mass densities under 20-30-40-50 N load conditions

Table 3 shows the average PM number densities and percentages of PM number densities. When the table is examined, all PM sizes showed a decreasing trend as the load increased. If a percentage comparison is made for the data obtained in each sample, PM 0.5 and PM 1.0 percentages increased as the load increased. PM 2.5, PM 4.0, and PM 10 particles tend to decrease with increasing load. This situation shows that the dust particles in the lining samples become smaller with the increase in the applied load. In the study on the subject in the literature [11], the number concentration is 180000-280000 #/cm^3, although it varies according to the specially produced samples. Lower measurement results were obtained in commercial lining experiments. This is a positive result in terms of the amount of PM emitted to the environment.

The snapshots of the measured PM number density by magnitude are shown in Figure 3. The PM number density plots show similar results to those described in the mass density plots.

Table 3. PM number densities and PM percentages at different loads

Load (N)	PM Type				
	0.5**	1.0**	2.5**	4.0**	10**
20	104994.3	145755.1	161194.3	164049.9	164679.6
	14.18*	19.68*	21.76*	22.15*	22.23*
30	103727.2	141084.4	154482.2	156955	157502.2
	14.53*	19.77*	21.64*	21.99*	22.07*
40	102945.5	138554	150916	153194.7	153700
	14.72*	19.81*	21.58*	21.91*	21.98*
50	102885.2	137309.5	148923	151061.2	151536.3
	14.87*	19.85*	21.53*	21.84*	21.91*

*Percentage rate, ** #/cm^3

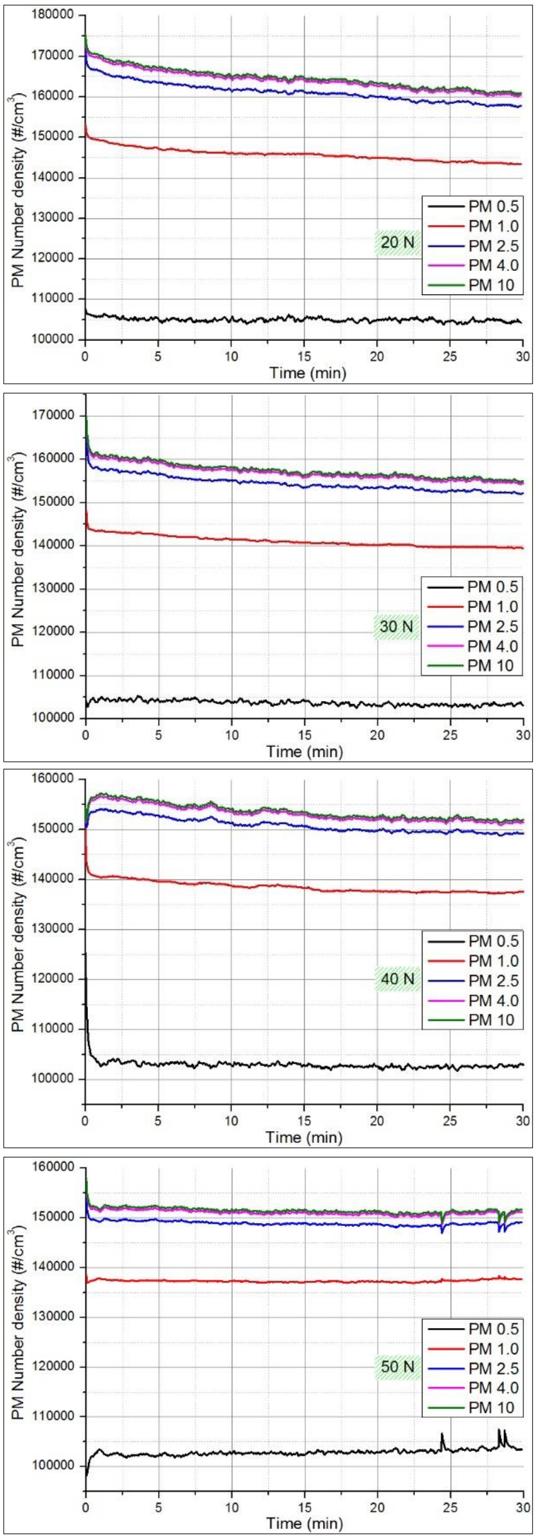

Fig. 3 PM number densities under 20-30-40-50 N load conditions

Figure 4 shows time-dependent particle sizes and average particle sizes. The average size of PM decreased as the load increased. This is a typical situation because the increasing load on the lining tends to reduce the size of the powdery substances produced due to wear.

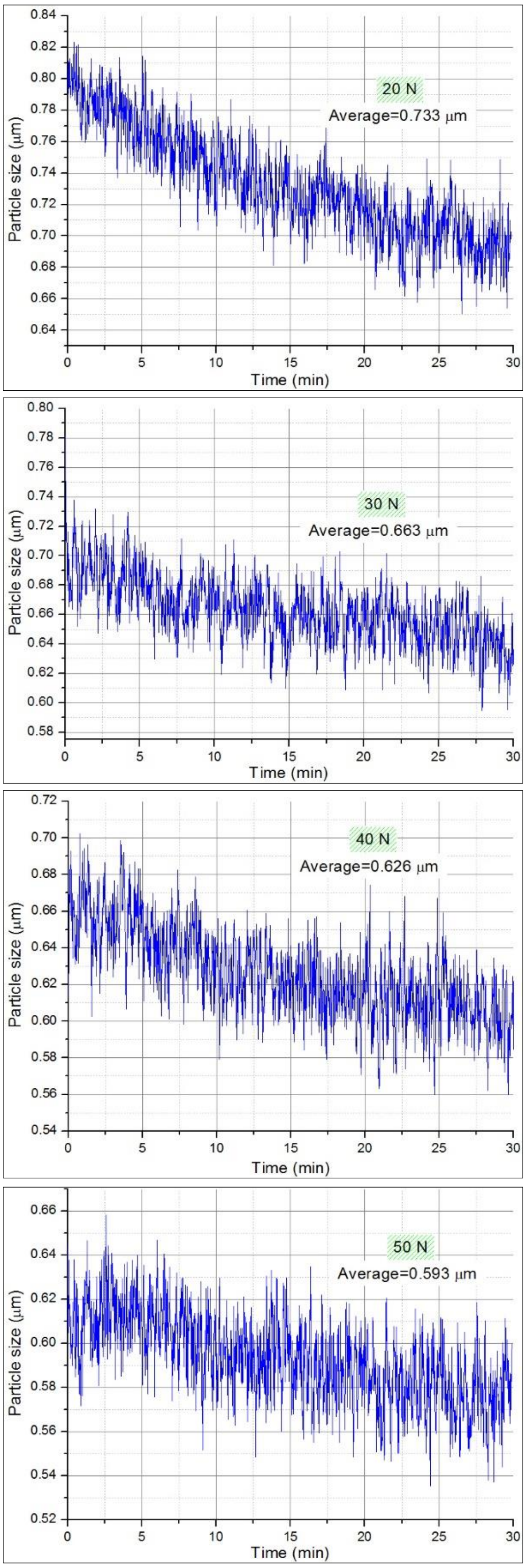

Fig. 4 PM sizes and average PM values under 20-30-40-50 N load conditions

IV. CONCLUSION

This study determined the size and average size of particulate matter resulting from the wear test of the vehicle brake pad used in commercial vehicles. These samples taken from the lining were subjected to an abrasion test in a pin-on type device, and the mass and number amounts and sizes of the particles that occur during abrasion were measured with a laser particle measurement sensor. The following conditions were determined due to the measurements that occurred due to wear during the experiment period.

- The average size of the powders resulting from abrasion is 0.733 µm at 20 N load, 0.663 µm at 30 N load, 0.626 µm at 40 N load, and 0.593 µm at 50 N load. The average size decreased as the load increased.
- Although the average bulk density values varied, they showed a decreasing trend with the increase in the load. The highest amount of particulate matter in bulk density at all load weights was measured at PM 10.
- In the numerical density results, the highest amount of PM in average and total number values was obtained in PM10. As the load on the lining increased, there was a decrease in number of concentrations in all PM classes.

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