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NUMERICAL DETERMINATION OF THE HEATING AND WEAR OF BRAKE PADS ON THE BASIS OF EXPERIMENTAL RESEARCHES

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Abstract: *The wear of brake pads is very important from the aspect of the reliability of the brake system, as well as from the aspect of environmental protection. In order to conduct the numerical research, first it was conducted the experimental research in the laboratory, where is defined the quarter of the vehicle mass, maximal pressure in brake installation and speed of the simulated vehicle. As the output from the experimental research, are obtained the values for the friction coefficient change during the braking process, as well as the change of the braking pressure and speed of the simulated vehicle. The outputs of the experimental research are the input for the numerical investigation, which was performed in the ANSYS software package. The results obtained by numerical analysis sign on the fact that the wear increases fast at the beginning of the braking process, while by further decrement of the brake disc angular speed, wear decreases too. The change of the wear is directly conditioned and with the change of the temperature of brake pads.*

Keywords: *wear, brake pads, experimental research, numerical investigation, ANSYS.*

1. INTRODUCTION

Today, the vehicle has become the integral part of everyday life. With one word, the nowadays life cannot be imagined without vehicles. Modern vehicles have more and more powerful engines from year to year, and it can develop high speeds, which means that can have a high kinetic energy. In order to avoid the violation of the safety of passengers and environment, the braking system must be made as such so it can transform the kinetic energy of the vehicle in some other energy type. When it comes to the braking system, it transforms the vehicle kinetic energy to the heat [1] which releases to the environment [2]. The pre-condition for successful and safe stopping is the transformation of the complete kinetic energy into the heat.

The reliability of the braking system does not depend only from the successful transformation of the kinetic energy into the heat, but also and from the condition of the braking system elements. The acting organs of the braking system are the brake disc and brake pads. Trough time, it comes to the wear of these elements, and it is necessary to check them out. The expected lifetime of brake pads, sometimes is defined trough the vehicle passed kilometres, with one pair of brake pads [3].

However, the lifetime of the same brake pads which can be used on different vehicles, is not always the same. The life time of brake pads depends from the vehicle mass, application frequency, braking intensity, vehicle speed and similar [4]. So, the parameter of passed kilometres, is not the most representative parameter, which should be taken into the consideration, because exist many influential parameters [5]. This means, that the conditions in which works the braking system, will affect on the contact between the brake disc and brake pads, what further will affect on the efficiency of the braking system [6].

Braking efficiency depends and from the brake pads thickness, because with the decrease of the brake pads thickness, comes to the decrease of the braking efficiency, what in worst scenario can cause the violation of the safety of the driver, passengers and other traffic participants [7]. The wear process of brake pads, is non-linear, variable and non-stable, what indicates on the fact that the lifetime is not fix, that is, cannot be predicted [8]. Besides the great influence of the wear on the traffic safety, should not forgot the fact, that the wear products affect on the people health and environment pollution [9].

The aim of the paper is the determination of the heating of acting organs of the braking system, as well as the determination of the wear of brake pads, during the one stop of the vehicle. The heating of the brake disc will be shown for the cases of experimental and numerical research, and it will be shown, how much the numerical results deviate from the experimental ones.

2. THE DESCRIPTION OF THE APPLIED TOOLS FOR THE RESEARCH

The experimental work conducted in this research, consists from two parts, and that from the experimental work conducted in the laboratory and from the numerical investigation. The reason for two-part research is because the wear of brake pads cannot be determined in the laboratory conditions. So everything measured during the laboratory research, will be used as the input for the numerical investigation.

2.1 Laboratory installation

The test rig for the laboratory testing of disc brakes, is shown on the Figure 1, while the scheme is given on the Figure 2.

Figure 1. The test rig for the laboratory investigations – BRAKE DYNO 2020

By observing the Figure 2, it can notice that the test rig consists from the drive part – electromotor (1) which is connected with the flywheel mass (5) through the electromagnetic clutch (2). The flywheel mass is supported by bearings (4) on the carry platform of the test rig (22) and it is connected with the shaft, which on one side is through the electromagnetic clutch (2) connected with the electromotor (1), while on the other side is the brake disc (6). The brake disc is connected with the shaft by screws. The role of the test rig is the testing of the braking system, so and other elements of the braking system are present. The brake calliper (27), which is necessary for braking, is connected with the carry plate (28). On one side of the carry plate is the brake calliper, while on the other is force sensor (19). The force sensor is connected with the carry platform of the test rig. The connection of the carry plate and carry platform is provided by revolution joint, which provides the force transfer from the brake calliper to the force sensor. This joint provides the effect of the seesaw.

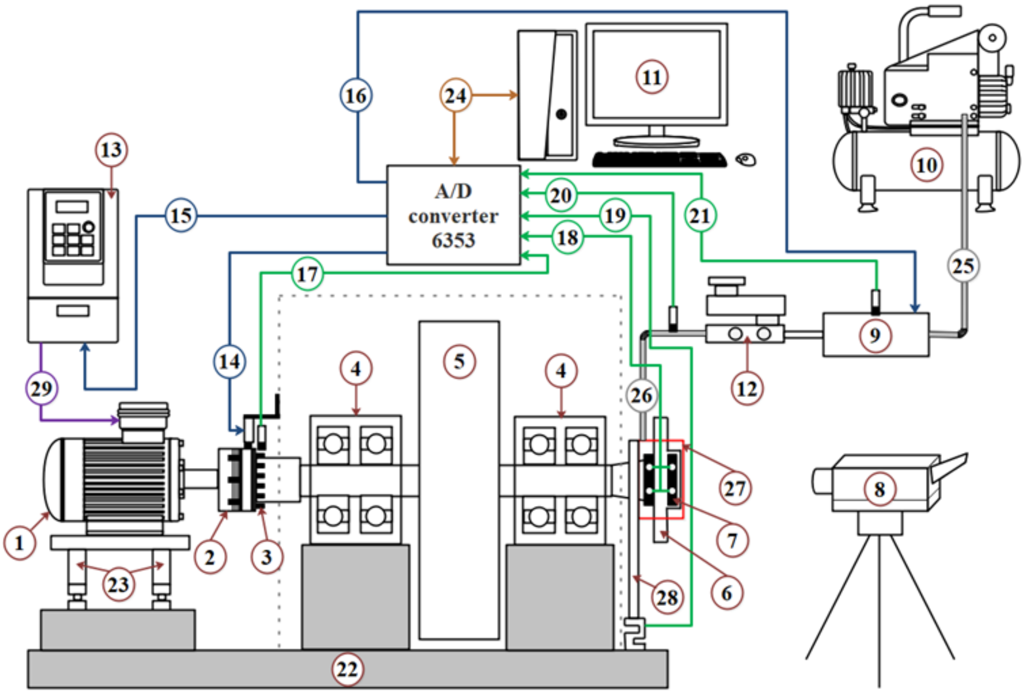

Figure 2. The scheme of the test rig for disc brakes testing – BRAKE DYNO 2020

The control of the test rig, is provided by the software made in LabView, which is installed on the PC (11). The software serves for the test rig control on the basis of the simulated vehicle data (vehicle speed and vehicle mass). The test rig is equipped with one disc brake, so this means that the test rig simulates the quarter of the vehicle. Different from the vehicle speed and mass, the braking pressure in hydraulic installation adjusts manually through the pressure regulator which is part of the pneumatic installation (9). The braking force is provided by the master brake cylinder (12), which sends fluid under defined pressure through the pipes (26), to the brake calliper (27). The pneumatic system (9) serves foe the master brake cylinder activation, as well as for the braking pressure regulation. With that, that the braking pressure is regulating manually, while the activation is automatized. More accurately, the pressure value which is regulated manually is the maximal value of the desired braking pressure. All signals sent for the test rig control, and received from the sensors, are collecting and transfer by A/D converter, which is connected with the PC (11) by cable (24). The achievement of the desired braking pressure is quite simple. The pneumatic installation is equipped with pneumatic cylinder which has a piston with greater diameter, in respect to the piston in master brake cylinder. By regulation of pneumatic pressure, and by proportion of the pistons of pneumatic cylinder and master brake cylinder, it is easy to define a pneumatic pressure which will provide desired hydraulic pressure.

The process of the laboratory investigation is followed by the defining of the working parameters, and it constant observation, while the experimental work lasts. During the entire experimental work are following signals from sensors, which means that are being followed: simulated vehicle speed (calculated from the rotational kinetic energy where the main information is taken from the rotational speed sensor – 17), braking torque (force sensor – 19), braking pressure (pressure sensor – 20), brake disc temperature (thermal imager – 8) and brake pads temperature (temperature sensor – 18). In each brake pad are mounted two temperature sensors, one on the entering side and other on the exiting side of the brake pad.

2.2 Numerical tool

In order to determine the wear of brake pads, an ANSYS/Transient Structural software package was used. The module Transient Structural provides simultaneous calculation of mechanical and thermal stresses. For the realization of the numerical investigation, it is necessary a virtual model, the material properties for each part and working parameters, which in this case were determined by the experimental work.

3. EXPERIMENT PLAN

The plan of the experiment is shown on the Figure 3. Firstly, it is necessary to conduct the laboratory investigations, which output will be used as the input for the numerical investigation. During the laboratory investigation, it is necessary to define the working parameters, that is, the quarter of the vehicle mass (300 kg), vehicle speed (100 km/h) and braking pressure (5 MPa). Before the measurement, it is necessary to provide the initial conditions, that is, the temperature in the laboratory should be 21 °C ± 1 °C, while the temperature of the disc brake should be 25,5 °C ± 0,5 °C. If this condition is satisfied, the measurement can start. The measurement results are saving on the PC, and after that some of the results are used for the inputs in the numerical investigation, while some are used for the comparison of the results between the laboratory and numerical results.

After conducted laboratory investigation, the next step is the numerical investigation. First step of the numerical investigation is the creation of the virtual model, Figure 4, (brake disc and brake pads), which by construction corresponds to the real model. Next step is the creation of materials, which by properties correspond to the real materials. Materials properties are given in Table 1. All this is necessary to create a numerical model which will give results closest possible to the results obtained in the laboratory.

After the materials are defined, the next step is mesh creation. The applied type of mesh in this case is a second order tetrahedral mesh. The reason for use of the second order mesh is the accuracy of the results. However, this type of mesh has disadvantages, that is, requires more time for calculation. The brake disc consists 21096 elements and 38938 nodes, the inner brake pad consists 840 elements and 1684 nodes, while the outer brake pad consists 824 elements and 1660 nodes.

The next step is the defining of the boundary conditions, that is the use of data taken from the laboratory investigation, Table 2. The output of the numerical investigation is the temperature of the disc brake elements and the wear of brake pads. First, it is necessary to determine if the developed numerical model gives accurate results, and this is achieving by comparison of numerical results with the results obtained from the laboratory investigation. As the criteria for the accuracy of the results, is defined that the temperature results obtained by numerical investigation, should not deviate more than 5% in compare to the results obtained in the laboratory. If this was achieved, it can proceed to the calculation of the wear of brake pads.

The wear amount is defining through the wear volume (V_w), which is calculating by equation (1) [10]:

$$V_w = \int dV = K_w \cdot v \cdot \int \frac{F_n}{H} \cdot dt \ . \qquad (1)$$

In the relation (1) applied parameters are: K_w - wear coefficient, v - sliding speed, F_n - normal force and H - material hardness. The wear coefficient for brake pads amounts $3.51 \cdot 10^{-5}$ mm^3/J [2].

In the case, when the difference between the results of the temperature obtained by numerical investigation, and temperature obtained in the laboratory, is greater than 5%, something must be corrected. First, is making the correction of the numerical model, that is, it is checking the model, the materials properties and boundary conditions. If all mentioned is correct, the next step is the correction of the mesh. That is, the mesh size is decreasing, all with aim to obtain more accurate results, results more approximate to the results obtained in the laboratory.

However, if all this don't give a positive result, on the output data, that is, on the temperature values, it is necessary to conduct the complete laboratory investigation from the beginning. Because, sometimes during the laboratory investigation, it can come to the measurement error. When the laboratory investigation is conducted again, the new results are using for the numerical investigation.

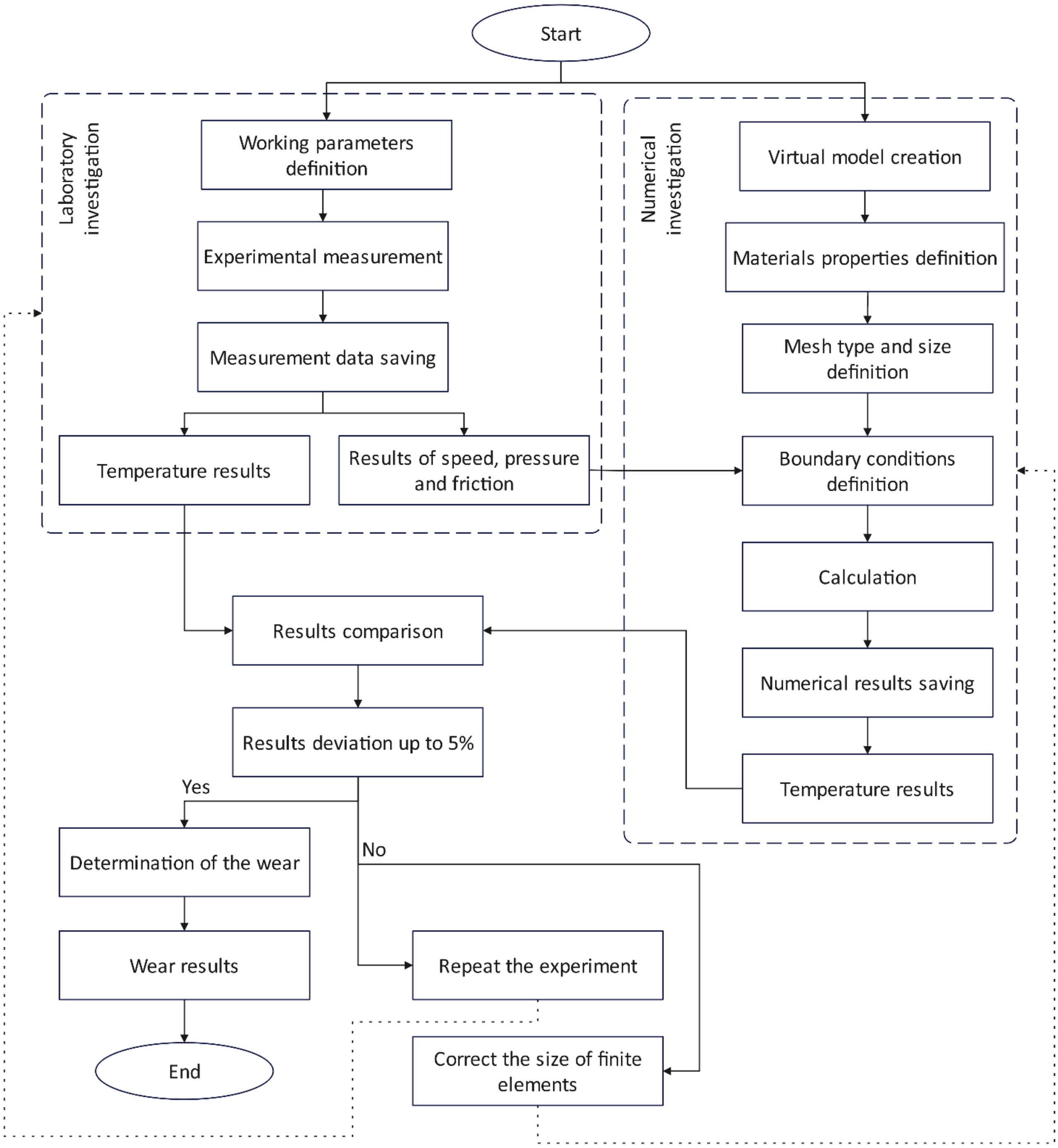

Figure 3. The alghoritm of the experiment plan

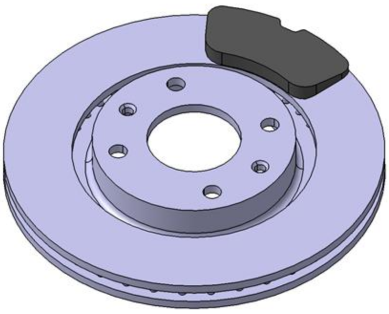

Figure 4. Disc brake 3D model

Table 1. Disc brake materials properties

Feature name	Brake disc	Brake pad
Density (kg/m^3)	7100	2300
Young's module (GPa)	118	20
Poisson's ratio (-)	0.32	0.3
Heat conductivity (W/m·°C)	53.3	3
Specific heat (J/kg·°C)	490	1200
Thermal expansion (1/°C)	$10.85 \cdot 10^{-6}$	$10 \cdot 10^{-6}$

Table 2. Boundary conditions

Time (s)	Friction coefficient (-)	Braking pressure (MPa)	Angular speed (rad^{-1})
0	0	0	91.34
0.25	0.37	2.28	90.87
0.5	0.38	4.25	85.51
0.75	0.40	4.93	78.49
1.00	0.41	5.02	70.34
1.25	0.42	5.04	61.95
1.50	0.43	5.05	53.46
1.75	0.44	5.05	44.97
2.25	0.44	5.04	36.26
2.5	0.45	5.04	26.88
2.75	0.45	5.03	17.99
3.00	0.45	5.01	8.82
3.25	0.32	4.88	0.00

4. RESULTS AND DISCUSSION

The first step for the results presentation is the comparison of the temperature values obtained by laboratory investigations and numerical investigations. How the results do not deviate above the defined range (maximal deviation is 3.73%), it can proceed to the calculation and presentation of the results of the wear of brake pads.

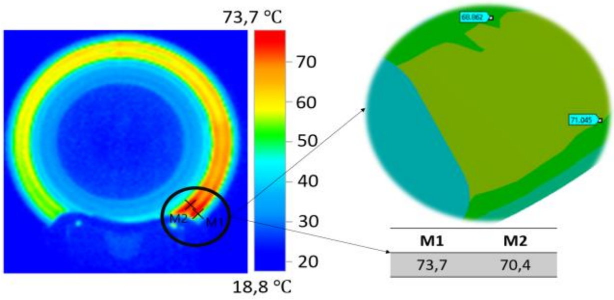

Figure 5. The comparison of the results

The wear value for brake pads is shown on the Figure 6. It can notice, that the greater wear is present in the case of the outer brake pad, in respect to the inner brake pad. The reason for this is so-called umbrella effect of the brake disc [11, 12], which causes greater pressure on the outer brake pad, and results with greater wear. The entire amount of the wear products mass for the inner brake pad is 9.5774 ng, while for the outer brake pad is 9.7278 ng, what is 1.5699% greater compare to the inner one.

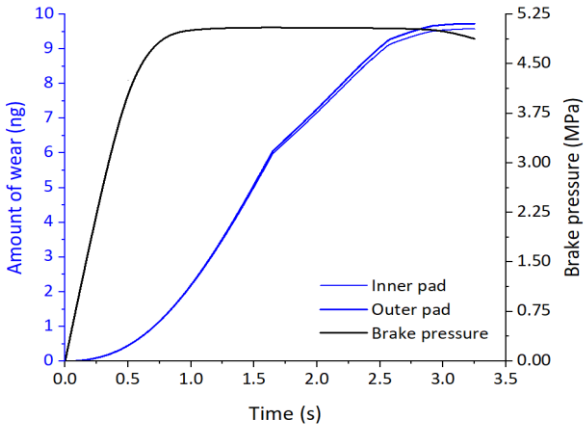

Figure 6. The amount of the wear of brake pads for one vehicle stop

At the beginning comes to the greater wear how for the inner so and for the outer brake pad, Figures 7 and 8. The reason for this is still great angular speed of the brake disc. This kind of behaviour continues further with the decrement of the angular speed of the brake disc, due to the braking pressure increment. The instant decrease of the wear of brake pads happens when the angular speed of the brake disc speed drops below the value 40 rad^{-1}. It can notice that the curve which describes the wear change, has similar shape as the curve which describes the change of the maximal value of temperature. The temperature on Figures 7 and 8, represents the temperature on the contact surface of the brake pad. The main difference in the curves of wear and temperature, is the noticeable phase late of the wear, what is logical because the wear follows the temperature rise. It can conclude that with the temperature increment, increases and the wear intensity [13].

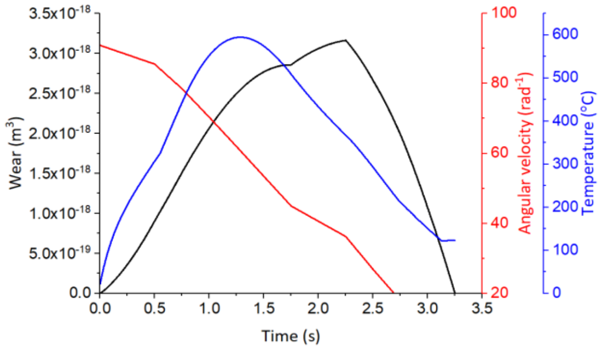

Figure 7. The influence of the angular speed of the brake disc and temperature of the inner brake pad on the wear intensity of the inner brake pad

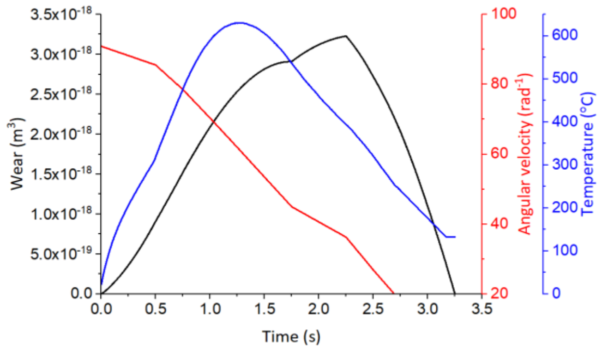

Figure 8. The influence of the angular speed of the brake disc and temperature of the outer brake pad on the wear intensity of the outer brake pad

By observing values of the friction (Table 2) and values of the wear of brake pads (Figures 7 and 8), it can notice, that with friction increment, increases and the wear of brake pads. On the friction value, influence have the temperature and the pressure between the brake disc and brake pads, so this means, that the wear, temperature, pressure and friction are connected.

5. CONCLUSION

The braking system of the vehicle is very important system. The violation of the working efficiency of the braking system, can cause the violation of the safety of all traffic participants. This violation followed by the wear of brake pads is not linear, and it is not-predictable, due to the influence of many factors. On the basis of the conducted research, in this paper, which consists from three parts, literature review, laboratory investigation and numerical investigation, aroused next conclusions:

- The wear of brake pads is non-linear, unstable and variable, that is, it is unpredictable.
- The conducted research procedure can be successfully applied for determination of thermal stresses of disc brakes.
- The numerical investigation can be successfully applied for determination of the wear of brake pads.
- The angular speed of the brake disc affects on the wear of brake pads.
- The value of the temperature in the contact of the brake disc and brake pads affects on the wear of brake pads.

The conclusions aroused from the research conducted in this paper, can be considered as very useful for future researches, such is the reduce of the time for the research, and application of numerical tools for the determination of the wear amount. In future researches should include and disc brakes different by construction, as well as by materials from which are made.

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