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EXPERIMENTAL ANALYSIS OF THE THERMAL BEHAVIOR OF BRAKE DISCS FOR DIFFERENT FRICTION COUPLES

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ABSTRACT

This work aimed to study the behaviour of car brake discs during braking, for different friction couplings. To simulate the braking coupling, as faithfully as possible and to obtain as accurate numerical data as possible, about the temperature of the discs, it was necessary to design and create an experimental stand. This stand was designed using the Catia V5 application and its construction was carried out using actual, ventilated and non-ventilated brake discs, whose movement was generated by an electric motor. The temperature of the discs was determined using temperature sensors and an Arduino module. The numerical data of the temperatures for the different friction couplings were collected in a real-time Excel file. The data interpretation was done according to the different friction couplings, such as cast-iron/wood, cast-iron/aluminium, cast-iron/standard brake pad material etc. The heating and cooling times of the two types of brake discs were analyzed, concluding the benefits of using ventilated discs for vehicle braking systems.

Keywords: brake, thermal behavior, ventilated disc, experimental stand, heating time, cooling time

1. INTRODUCTION

The automotive industry benefits from subassemblies obtained from other industries, whose concerns are improving quality and developing cost-effective and environmentally friendly products. One such series of components are brake discs and pads, which form friction couplings and actively contribute to road safety. This subassembly of the vehicle braking system must meet a series of requirements in order to fulfil its functional role and ensure safety in operation. One of the conditions that the pad-disc subsystem must meet is to maintain its physical and mechanical properties throughout its entire period of use. The influence of the temperature developed during braking could modify a series of mechanical or physical characteristics with repercussions on the effectiveness of the braking system [1].

From a technological point of view, brake discs are made of cast iron because it has good fatigue resistance and a high capacity for heat dissipation. This property is very important to prevent the discs from deforming or cracking when they are in contact with moisture [2]. The friction coupling required to achieve the braking process is completed by brake pads, which can be made of organic, ceramic or newer composite materials. All brake pads must ensure a coefficient of friction greater than 0.25 in order to generate the necessary braking force to stop the vehicle, safely [3], [4].

2. MATERIALS AND METHODS

Due to the impossibility of mounting sensors on the brake discs of the vehicle and collecting erroneous data, it was necessary to design and build a brake stand that would reproduce the braking system as faithfully as possible. The design of the stand was made using a computer-aided graphics application, Catia V5 R21. All the components of the braking system were modelled and incorporated into a metal frame. The main modelled components of the hydraulic braking system were: the brake pedal, the brake servo, the brake pump, the fluid reservoir, the rigid and flexible pipes, connecting elements, brake calipers with discs and an electric motor, as shown in Fig. 1.

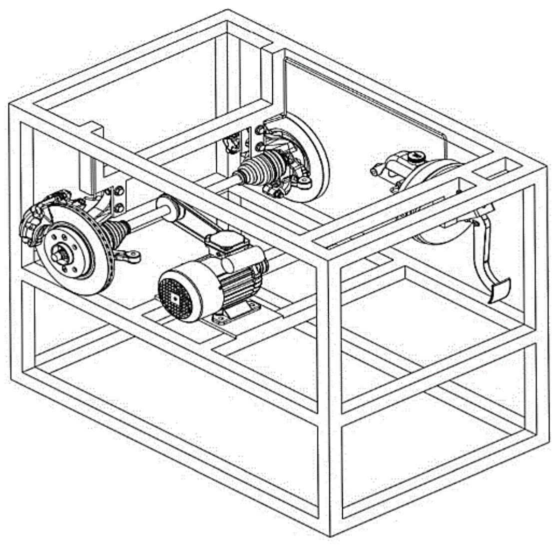


Fig. 1. Modeling the brake stand using the Catia V5 R21 application

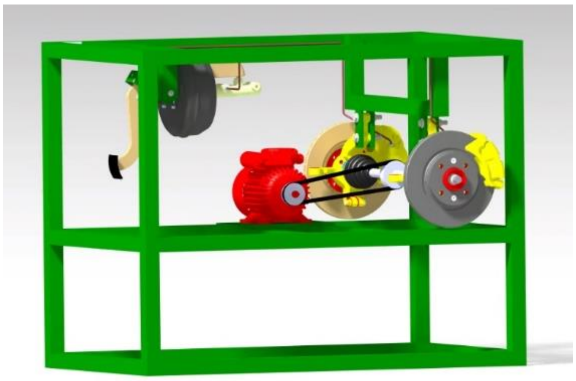
In order to create the stand, an electric motor was used to generate the necessary movement and transmit it through a belt to the shaft. The shaft, then, transmits the motion to the brake discs in order to simulate braking. The shaft is equipped with an unventilated brake disc at one end, and a ventilated brake disc at the other end. The installation of these different discs was done so that the braking conditions are the same for both the ventilated and unventilated discs, as shown in Fig. 2.

Fig. 2. Assembly of the braking system with ventilated and unventilated brake discs

The subassembly of the described braking system is connected to a brake servo pump, which also has a brake fluid reservoir in its immediate vicinity, as shown in Fig. 3. When the brake pedal is pressed, it acts on the servo mechanism through a rod, which amplifies the force of the pedal and transmits it further to the brake pump. The brake pump converts the received force into pressure, which pushes the brake fluid through rigid and flexible pipes. Subsequently, through cylinders, the pressure of the fluid in the pipes acts on the disc brakes. As for the role of the fluid reservoir in the braking system, it acts to compensate for fluctuations in the volume of fluid in the braking system circuit.

Fig. 3. Brake servo pump and brake fluid reservoir

The brake stand was made according to the project and by respecting the mounting conditions of the braking system subassemblies, as shown in Fig. 4.



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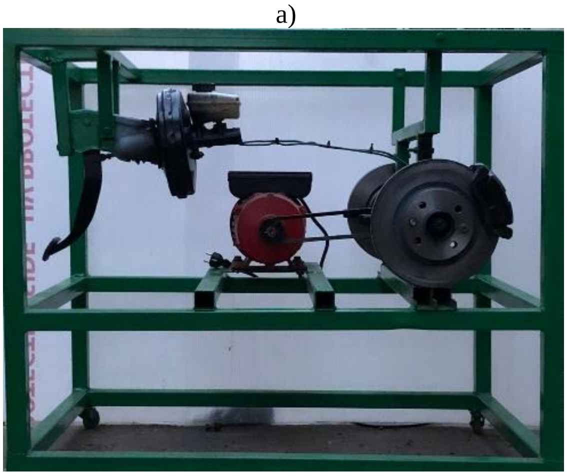

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Fig. 4. The designed and manufactured brake stand

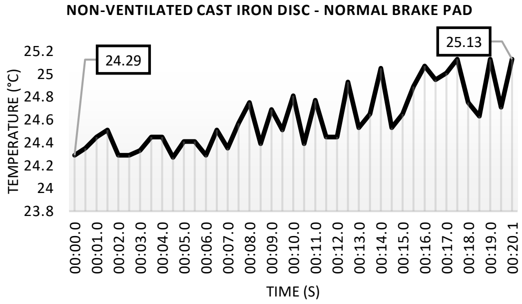
In order to analyze the comparison of temperatures developed at the level of the discs, in the case of brake pads with different friction materials, an Arduino UNO R3 module was used. An Arduino module consists of an Atmel AVR microcontroller with 8, 16, or 32 bits with complementary components that facilitate programming and incorporation into other circuits. This module, which collects data using temperature sensors, can save the data in Excel and, thus, it makes their analysis easier, [5].

In order to collect data, the temperature module was calibrated using a container with water and ice, as well as an Optris PI 160 thermal imaging camera. The sensor was mounted on the disc and the Arduino module was connected to a laptop. Ordinary brake pads were used for both the ventilated and non-ventilated discs, as well as some different materials to observe the influence of different materials on the brake disc temperature, [1], [5].

3. RESULTS

The collected data, both from the ventilated and non-ventilated discs, were saved and analyzed in Excel. Thus, the brake pedal was actuated for 20 seconds, with a constant force of 50 N.

The first test was conducted with normal brake pads, with the same characteristics for both brake discs. As shown in Fig. 5, it can be observed that in the case of normal brake pads, the temperature difference between the initial temperature of the brake disc and the final temperature in the ventilated disc, 1.82°C, is higher than that in the non-ventilated disc, 0.84°C.



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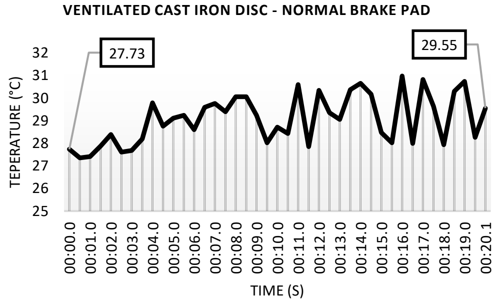

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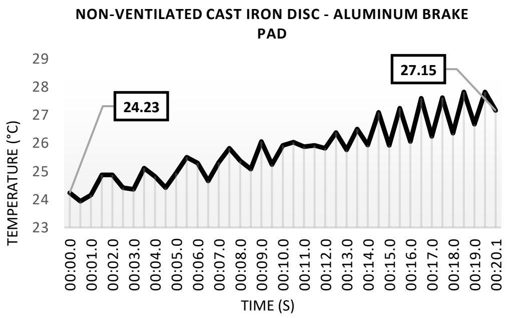
Fig. 5. The variation in brake disc temperature when in contact with normal brake pads

The second test was conducted under the same conditions, this timeusing an aluminium brake pad. The braking time was also 20 seconds, and it was observed that, both in the case of the non-ventilated and the ventilated disc, the temperature increased to a value of 27.15°C, with a greater difference recorded for the non-ventilated disc, as shown in Fig. 6.



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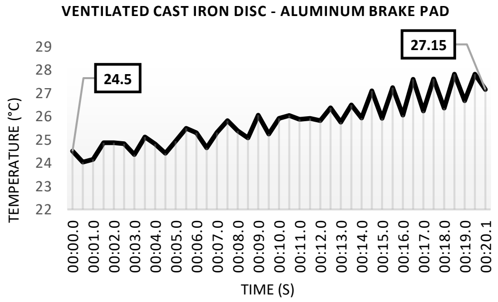

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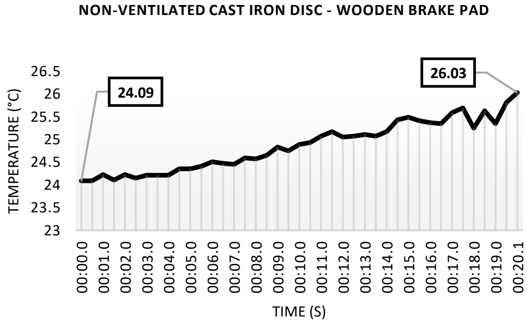
Fig. 6. Variation of brake disc temperature in contact with aluminum brake pads

In the third test, an organic material, wood, was used as the brake pad, with the same shape and contact surface as the original brake pads. It was found that, in this case, the temperature difference between the two discs was 1.94°C for the non-ventilated disc and 2.32°C for the ventilated disc, as shown in Fig. 7.



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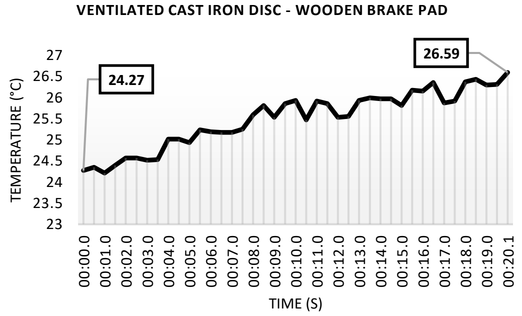

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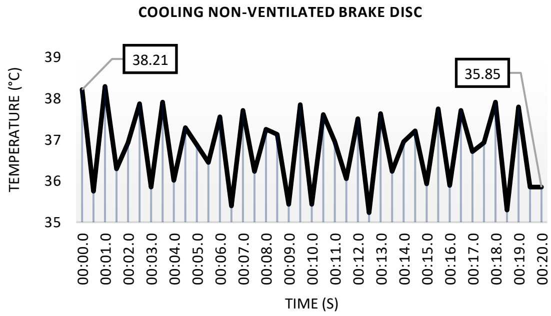
Fig. 7. The variation of brake disc temperature in contact with wooden brake pads



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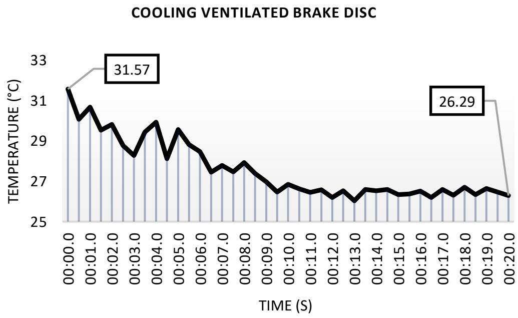

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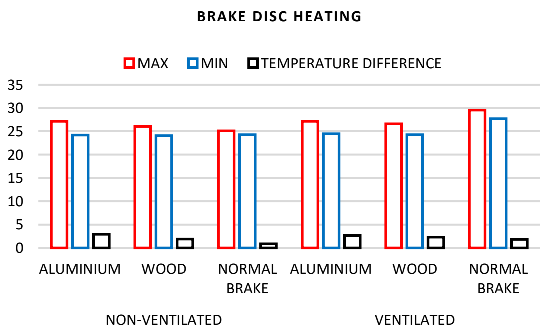
Fig. 8. Cooling of the brake discs for 20 seconds

The cooling of the brake discs was achieved by releasing the brake pedal and allowing natural ventilation. As shown in Figure 8, in the case of non-ventilated discs, the temperature decrease occurs in a jerky manner, meaning the temperature decrease of 2.36 °C occurs slowly, and the temperature sensor records this decrease in certain areas, while in other areas it cools more slowly. In the case of ventilated discs, the temperature change is somewhat linear, and the temperature decreases by approximately 4.98 °C in 20 seconds. Cooling was measured simultaneously and in the same time interval for both discs.

4. CONCLUSIONS

The importance of braking systems in achieving an adequate level of active safety for automobiles has led to the development of various methods for their verification. Based on this idea, we designed and built a testing rig for ventilated and non-ventilated brake discs, with which we conducted a series of laboratory tests on heating and cooling of these discs.

After analyzing the heating and cooling of the brake discs (Fig. 9), the following conclusions can be drawn.



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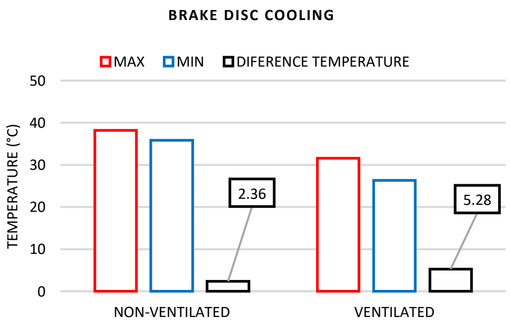

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Fig. 9. Analysis of the heating and cooling of the two types of brake discs

- The ventilated disc equipped with normal brake pads heated up faster than the non-ventilated disc, with a temperature difference of approximately 1°C between the two discs;
- When aluminum brake pads were used as the friction material, both the ventilated and non-ventilated discs heated up to 27.15 °C, but the difference between the initial and final temperatures was approximately the same (2.92 °C for the non-ventilated disc as compared to 2.65 °C for the ventilated disc).
- When wood was used as the friction material, it was observed that the ventilated brake discs heated up faster, by 2.32°C.

It is observed that in two of the three analyzed cases, the ventilated disc heated up more than the non-ventilated one, the difference in temperature being determined by the friction material used. In the case of aluminum brake pads, the heating was relatively the same. Thus, regardless of the friction material used for the brake pads, the ventilated disc heats up more than the non-ventilated one, due to the smaller volume of material in the ventilated disc. Testing for cooling of the two discs led to the conclusion that the use of cooling fins for the ventilated disc substantially increases the temperature difference after 20 seconds, between the two types of discs.

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