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MODELING AND ANALYSIS OF THERMAL BEHAVIOUR FOR BRAKE DISCS

BY

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Abstract. Focusing strictly to the braking assembly system, it is an important key factor for safety, does not matter if it can be found on cars, motorcycles, planes or bicycles. The principal aspect is to transform the energies that act on the system, which are kinetic and potential, then leads to a speed decrease of the vehicle until it stops.

The purpose of this paper is to analyze five possible variants of the geometry of the brake disc, each geometry being different from the other. Because for a more efficient release of heat, the five chosen geometries of the discs have on their surface vanes, holes, in order to remove heat from their surface. For the actual making of the discs, the chosen models were made and designed in the CATIA V5 design program.

The next step in this work was to perform analyzes and simulations for the selected disks. At the same time, the material chosen for them was considered. The 3D models were imported into the ANSYS analysis program, where individual analyzes were performed for each brake disc, and a comparison was made between the values of each one.

Keywords: modelling, brake, simulation, disc, thermal, analysis.

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1. Introduction

Starting with the braking disc, which is an important component from the braking system assembly. One of its main role, it is to stop the wheels of a moving vehicle, then it is an key factor of heat dissipation during the braking process (Gongyu and Rongyu, 2018).

The primary criterion placed on brake discs is their ability to dissipate heat quickly in the external environment. Braking capacity is low when the braking system is overheated, so then the geometry of each individual is an important factor before production process.

Factors involved on the disc surface are mechanical and thermal stress, which usually has high values once the braking process begins. Stresses from the thermal point of view are the main source of risk for the braking system during severe braking, which occurs when driving cars in cities. The performance of the brake disc assembly is influenced by the friction coefficient and the entire disc geometry, consisting of components that have essential roles. All of this can cause them to wear down quickly, change shape, or be damaged. The temperature distribution on the disc can be used to detect the thermal stresses that occur during braking process and to identify the high stress zones.

Numerous studies have been carried out over time in this field, where great attention has been paid to the results obtained, as this field is of great interest to car manufacturers and beyond, because the braking system is an important factor in road safety. The studies focused on the diversity of existing disc variants and the influence of geometry on its behaviour during the braking process.

This study is based on the analysis of the brake disc, considering their geometry, by modeling a well-defined number of discs, where the determining factor between them will be the geometry on the surface of the brake disc.

Given the fact that brake discs are found in many fields of activity and are found on many vehicles, depending on the field in which they are used and the type of vehicle and the demands to which they are subjected, they diversify into several types.



Fig. 1 – Brake disc for cars.



Fig. 2 – Brake disc used for light weight vehicles.

2. Constructive variants of the discs and their thermal analysis

Fig. 1 shows a brake disc equipped on a mid-range car, where the thermal demands are not very high. Compared to this, Fig. 2 presents a variant of a disk used in this analysis (Siddharth *et al*., 2019). There are construction differences between them, the one used for vehicles has a greater thickness and has ventilation channels, and the one in our study is simpler from a geometric and constructive point of view. These types of discs studied and analysed in the paper will often be used on motorcycles, bicycles, tricycles or other lighter vehicles, where the demands are not very high (Manthan and Balbir, 2018).

The structure of the paper is based on the modeling of five disc variants, which will be presented during the paper, which will then be analysed from a thermal point of view by thermal analysis, the analysis mode being also presented, and then to be done a study of the materials used, for a better efficiency.

For the beginning, the 3D models of the discs were made, according to the dimensions given in Figs. 3 and 4. Subsequently, various geometries of the disk contact surface were made so that they were different from this point of view, in order to analyse the thermal analysis.

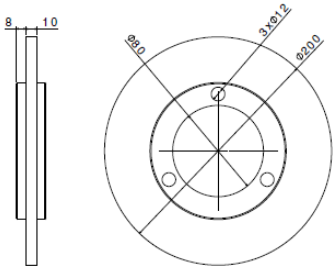


Fig. 3 – General dimensions for brake discs.

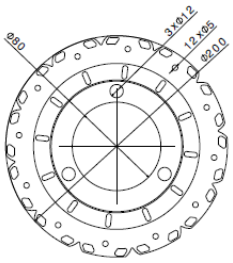


Fig. 4 – General dimensions for brake discs.

Fig. 5 shows the dimensions chosen for the brake pad, they correspond to the actual dimensions used in the automotive field.

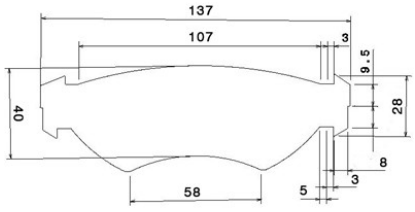


Fig. 5 – General dimensions for brake pads.

Because these brake discs are often used in areas where the strength and heat levels are lower, compared to the brake discs used in cars, the geometry and construction of the discs used in this work is more simple and designed for increased thermal efficiency (Chetan *et al*., 2018).

The modeling program used to create each constructive disc variants was CATIA V5 modeling software. Each variant is presented in Figs. 6 to 10 and their mesh network (*nodes and elements*) in Figs. 11 to 15. During the finite element simulation, an individual thermal analysis was performed for each variant of the disc, starting from the first variant to the fifth, to simulate the working process as real as possible (Metha *et al*., 2020).



Fig. 6 – 3D model for the first disc variant.



Fig. 7 – 3D model for the second disc variant.

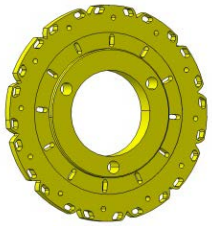


Fig. 8 – 3D model for the third disc variant.

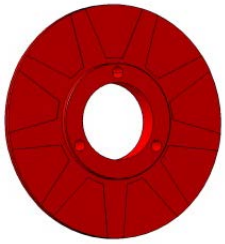


Fig. 9 – 3D model for the fourth disc variant.



Fig. 10 – 3D model for the fifth disc variant.

Using ANSYS simulation program, which is one of the best simulation software on the market, it was possible to perform a finite element analysis for the modeled disks. As a preliminary step before performing the actual analysis, Figs. 11 to 15 shows the network of nodes and elements for each individual disk. A short conclusion from this step is about the number of nodes and elements, the mesh network, which can be seen that as the complexity of the disk is higher, this leads to an increasing number for nodes and elements for the entire disc geometry (Vishal *et al*., 2018).

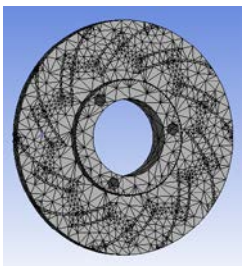


Fig. 11 – Mesh network for the first disc variant.

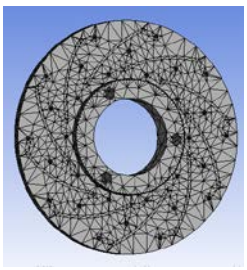


Fig. 12 – Mesh network for the second disc variant.

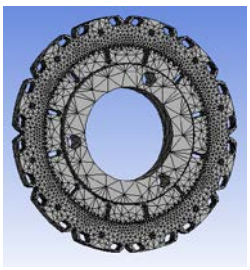


Fig. 13 – Mesh network for the third disc variant.

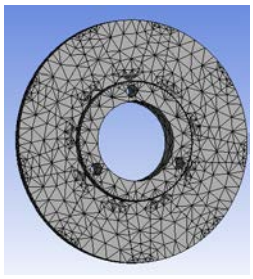


Fig. 14 – Mesh network for the fourth disc variant.

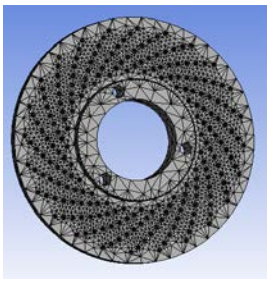


Fig. 15 – Mesh network for the fifth disc variant.

A main step before carrying out the thermal analysis was the application of some constraints to define the process that takes place. The braking process was recreated as accurately as possible with the one that actually takes place in a braking system. The thermal field appears when a pressure is applied to the surface of the rotating disk due to the movement of the wheels. Thus, a brake pad was modeled and a pressure of *20 MPa* was applied on their surface.

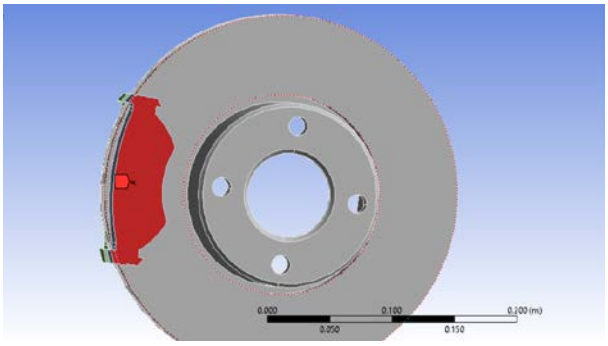


Fig. 16 – Pressure constrain on brake pads.

Fig. 16 presents the process of applying the pressure of *20 MPa* by the brake pads on the contact surface of the brake disc. This simulates the braking process at a more simplified level than the one that takes place in reality, because a simpler version of it is used, where only the main elements are included, namely the brake disc and the brake pads, the others elements being neglected and then Fig. 17 shows the area where the contact between the brake pad and the disc will be made, the area where the disc temperature will be recorded, following the disc-brake pad contact.

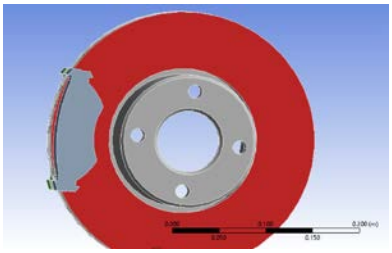


Fig. 17 – Contact zone for brake discs.

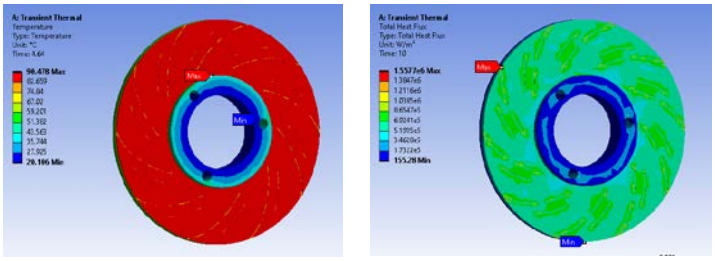
2.1. Disc analysis results for thermal contact

The following figures presented below, from Figs. 18 to 22 presents the results from thermal analysis performed for all five types of discs.

During thermal analysis, thermal flow load was simulated, to see the transmission of heat across flat surfaces, edges. It also adds energy to a body over time.

In the first part of the thermal analysis, the thermal results for each disk will be presented, from where the results for the temperature and heat flux parameter emerge, being important in the thermal analysis carried out. For this analysis, heat flux describes the rate of *heat energy* that passes through a surface.

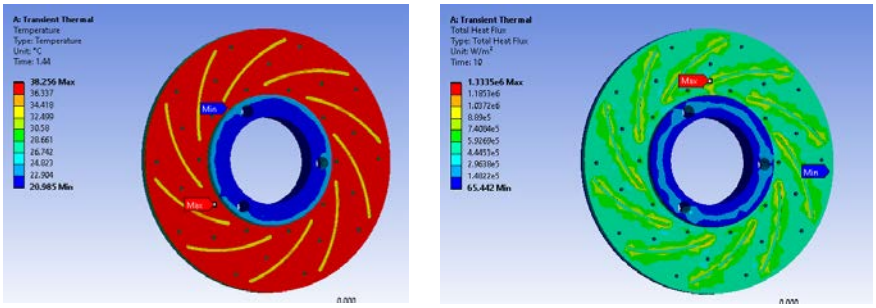
Thus, in the following figures are presented individually the temperature graphs for each disk variant, following that at the end of the chapter, all the values will be centralized to highlight them and make a comparison between the disc variants used.



a) Temperature b) Heat flow

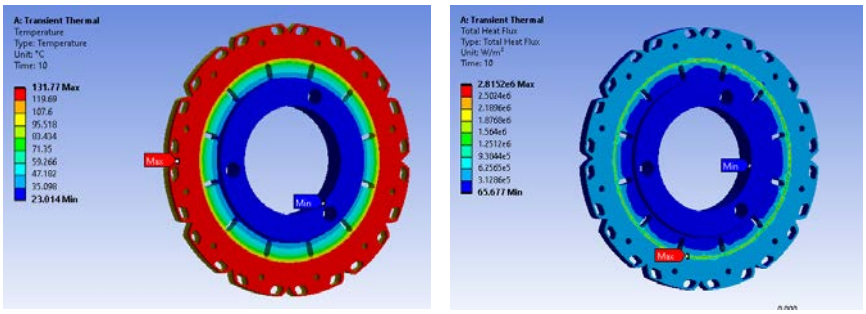
Fig. 18 – Thermal parameter results for disc number 1.

Starting with the first disc variant, it is observed that at the end of the braking process, the maximum temperature on the contact surface of the disc is degrees *179.62°C*, which is a reference value for the other analysis to be performed, and for the heat flux value, it is *1.5577e+6 W/m*^{2} .



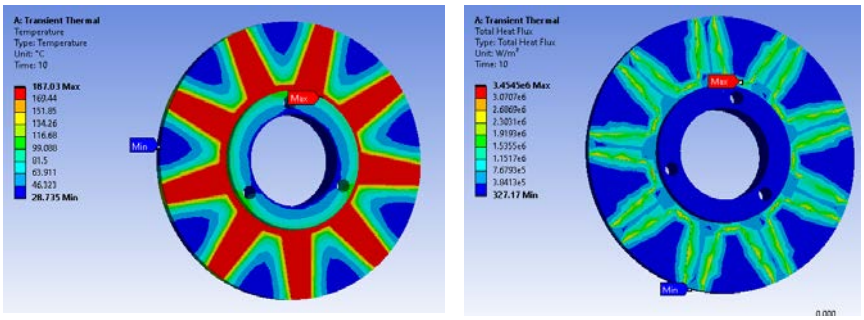
Temperature Heat flow

Fig. 19 – Thermal parameter results for disc number 2.



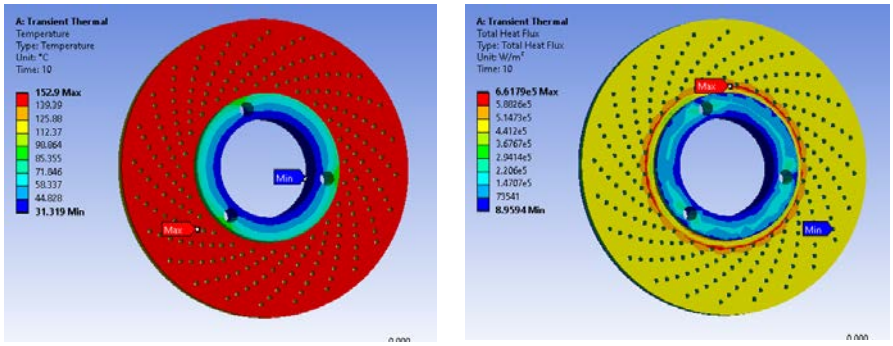
Temperature Heat flow

Fig. 20 – Thermal parameter results for disc number 3.



Temperature Heat flow

Fig. 21 – Thermal parameter results for disc number 4.



Temperature Heat flow

Fig. 22 – Thermal parameter results for disc number 5.

For the analysis performed, three different types of material were considered, namely semi-metallic, gray cast iron and ceramic. Initially, all five disks analysed will have the same type of material, namely semi-metallic. Subsequently, for the best thermal disc version, the other two alternative materials will be used to observe their thermal behaviour under the same analysis conditions.

Table 1

Properties of materials used in brake discs

Material Properties Used in Thermal Analysis	Ceramic	Semi Metallic	Cast-Iron
Thermal conductivity	32 [W $m^{-1}C^{-1}$]	60.5 [W $m^{-1}C^{-1}$]	52 [W $m^{-1}C^{-1}$]
Density	3750 [kg m^{-3}]	7850 [kg m^{-3}]	6999 [kg m^{-3}]
Specific heat	786.6 [JKg^{-1} C^{-1}]	434 [JKg^{-1} C^{-1}]	499.6 [JKg^{-1} C^{-1}]
Poissons ratio	0.27	0.3	0.28
Coefficient of linear expansion	2.6 10^{-6} [K^{-1}]	0.12 10^{-6} [K^{-1}]	0.11 10^{-6} [K^{-1}]
Young Modulus	24 [GPa]	20 [GPa]	110 [GPa]
Bulk Modulus	1.57e+11 [Pa]	1.66e+11 [Pa]	6.21e+10 [Pa]

2.1.1. Thermal analysis results for first disc variant

For the analysis performed in this paper, the ANSYS analysis program produced representative graphs for these results.

From the resulting graphs, the temperature variation can be observed during the braking process, the time being 10 seconds for the analysis performed. After representing the graphs, there were three values of the resulting temperature, for each type of disk, namely: minimum temperature (*red line*), average temperature (*blue line*) and maximum temperature (*green line*) recorded on the surface of the disk.

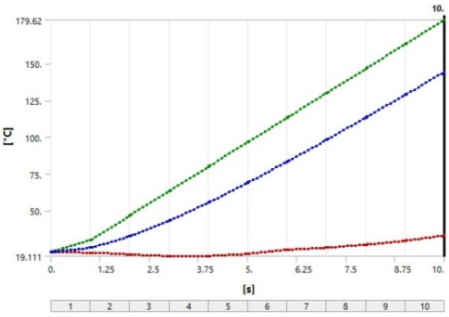


Fig. 23 – Resulted stats for temperature parameter - disc number 1.

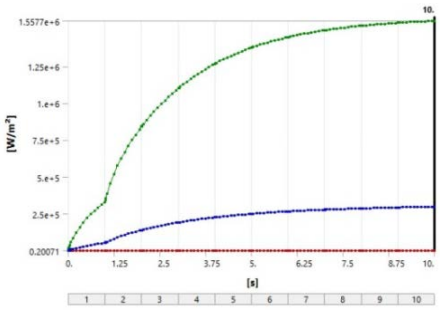


Fig. 24 – Resulted stats for heat flow parameter - disc number 2.

The geometry and the brake disc design used for this first case was relatively simple, and as for the following four variants, the material used was semi-metallic.

The results from the thermal analysis achieved for this type of disc, show a maximum temperature of *179.62°C*, presented in Fig. 23 and it was presented on disc surface during a braking interval of 10 seconds.

Moving on to the next Fig. 24, here is presented the values of heat flow during time for the same disc surface.

2.1.2. Thermal analysis results for second disc variant

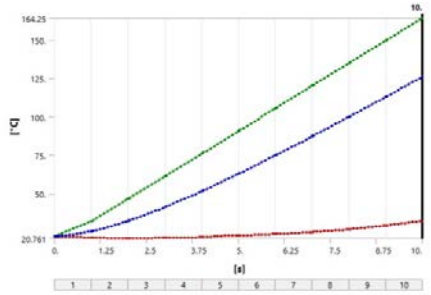


Fig. 25 – Resulted stats for temperature parameter - disc number 2.

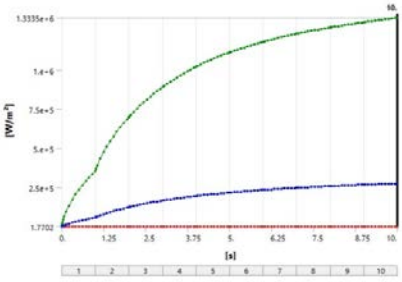


Fig. 26 – Resulted stats for heat flow parameter - disc number 2.

Compared to the first case, the difference between the first and this case, is the drilling holes, which is an important factor for brake discs.

Their main role is to maximize the ventilation and cooling the surface of the disc. As it can be seen in Fig. 25, it is a temperature difference between the first and the second disc variant, for the last one, the maximum temperature value is up to *164.25°C*. In Fig. 26 is presented the heat flow for the second disc variant, a lower value was obtained, compared to the first variant.

2.1.3. Thermal analysis results for third disc variant

For third analysed case, a brake disc inspired from motorcycles was designed. Processing, ventilation drilling and the design aim to minimize the brake disc weight and to obtain a maximum coefficient for thermal heat.

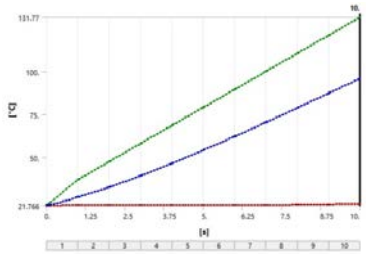


Fig. 27 – Resulted stats for temperature parameter - disc number 3.

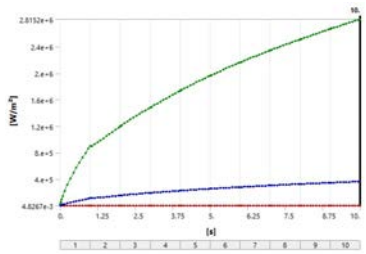


Fig. 28 – Resulted stats for heat flow parameter - disc number 3.

The results obtained from the thermal analysis indicates the lowest temperature, compared to other disc that were tested to thermal analysis. Maximum value of the temperature recorded on disc surface was *131.77°C*, which can be seen in figure 27, as from heat flow coefficient, the maximum value obtained was *2.8152e+6* W/m^2, which is presented in figure 28. The thermal analysis for third disc variant obtained the lowest values for temperature parameters, temperature and heat flow both, which means that the design adopted for it was the most efficient from thermal point of view.

2.1.4. Thermal analysis results for fourth disc variant

The fourth variant of the disc has a simple pattern on its surface, the thickness remains the same as for the others discs, 10 mm thickness (Sharath and Junling, 2017).

This design and the drills adopted for the contact zone makes a variant of this brake disc less likely in reality, because its efficiency and rigidity structure is much lower compared to the other variants.

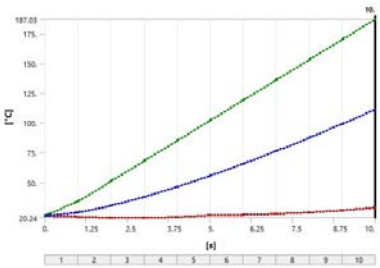


Fig. 29 – Resulted stats for temperature parameter - disc number 4.

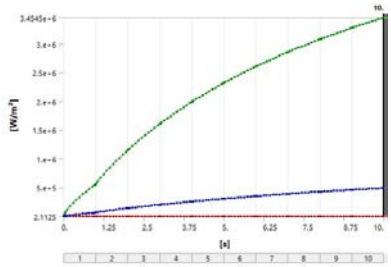


Fig. 30 – Resulted stats for heat flow parameter - disc number 4.

The model and geometry of the disc do not allow an efficient cooling and elimination of heat flux, so a large quantity of heat accumulates during its use, the temperature value being the highest, of *187.03°C*, see Fig. 29 for more details.

Same from the point of view of the thermal flow, at this variant the highest thermal flow among the variants used in the analysis, maximum value was *3.4545e+6* W/m^2, from Fig. 30.

2.1.5. Thermal analysis results for fifth disc variant

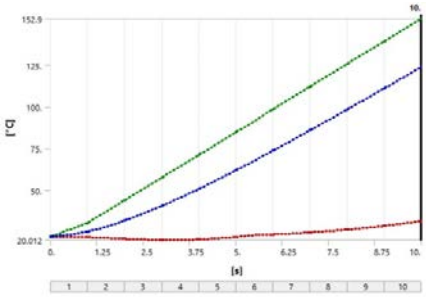


Fig. 31 – Resulted stats for temperature parameter- disc number 5.

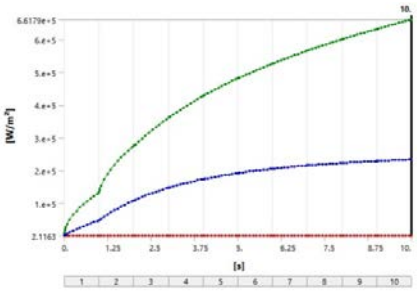


Fig. 32 – Resulted stats for heat flow parameter- disc number 5.

The fifth and the last disc variant which was subjected to a thermal analysis in this research, has a complex geometry which include several ventilation channels and perforations on the entire disc surface and contact zone, it was chosen an semi metallic material, and the next important parameter was the disc thickness, which was 10 mm. The results from the thermal analysis for this type of the disk variant, the maximum temperature presented on the disc surface was *152.9°C*, which is presented in Fig. 31. This disk variant has the best behavior in terms of temperature from the entire sample of discs.

Fig. 32 present the value for the heat flow during 10 seconds of heat analysis.

Table 2

Temperature parameters values for brake discs

Disc Variants	Temperature [°C]	Heat Flow [W/m^2]
First disc variant	179.62	1.5577e^{+6}
Second disc variant	164.25	1.337 e^{+6}
Third disc variant	131.77	2.8152e^{+6}
Fourth disc variant	187.03	3.4545e^{+6}
Fifth disc variant	152.9	6.661e^{+6}

3. Additional materials for braking discs

The next step is that for the best version of the disc, from a thermal point of view, in this case the third version, to use another two materials. Thus, thermal analysis were performed for the cast iron disc and for the ceramic disc (Pinca-Bretotean *et al.*, 2020).

For the initial analysis case, the same material was used for all brake discs, which is semi-metallic.

In the second phase of the simulation, the material change was made, which are cast iron and ceramic material. Their properties for each material used was presented in Table 1.

3.1. Cast-iron alternative disc material

Cast irons are indicated to produce brake discs because besides the low costs of the production, they have very good thermal conductivity coefficient, which leads to a good dissipation of the heat generated during brake process, which is a main characteristic of this kind of automotive part

In the Figs. 33 and 34 are presented the results from thermal analysis for cast iron material, for maximum temperature and heat flow.

This material has better thermal properties, compared to the semi-metallic material, and this can be seen from the thermal analysis performed, maximum temperature value on disc surface was *123.33°C.*

Figs. 35 and 36 show the variation of the temperature and heat flow for this type of material.

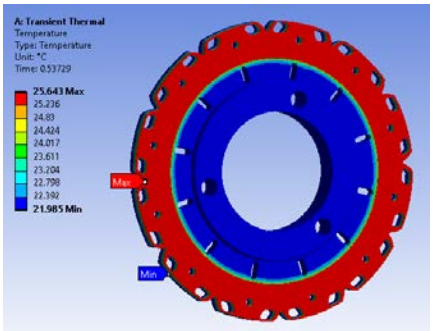


Fig. 33 – Temperature values for cast-iron.

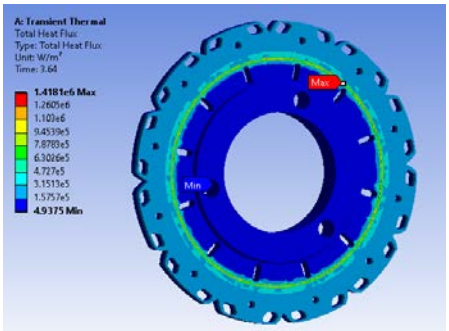


Fig. 34 – Heat flow values for cast-iron.

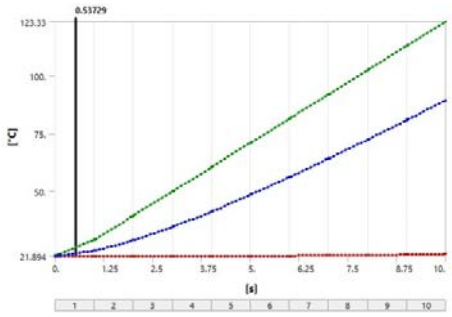


Fig. 35 – Resulted stats for temperature parameter - cast-iron material.

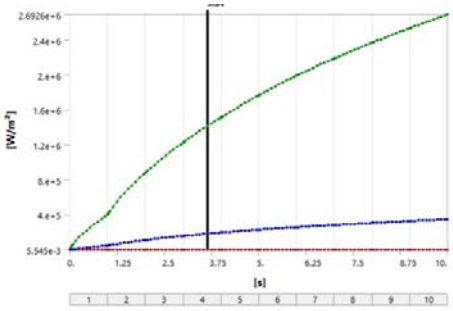


Fig. 36 – Resulted stats for heat flow parameter - cast-iron material.

3.2. Ceramic alternative disc material

For this material change was used the ceramic material, because is often used by car manufacturers for their top cars, due to the improved thermal properties and advantages offered.

Discs made from ceramic are similar to the type of semi-metallic or cast iron, but the density is more higher and the effect is that it gives more durability to the entire brake disc. Fine copper strands are also inserted into them to aid boost friction and heat conductivity, which is an advantage.

Comparing other types of material used for brake discs, the ceramic material has one of its working property which is less dust absorption on its surface during working period. The main disadvantage of ceramic is the cost, a higher manufacturing cost and a production cost, because in the actual market it is the most expensive brake disc (Vikas *et al*., 2016).

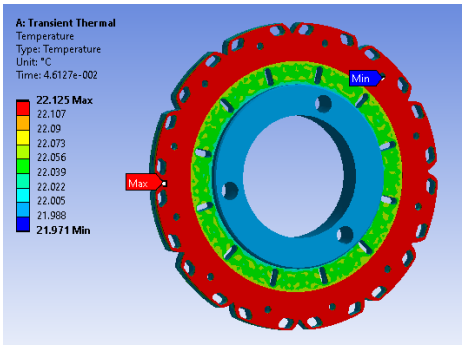


Fig. 37 – Temperature values for ceramic.

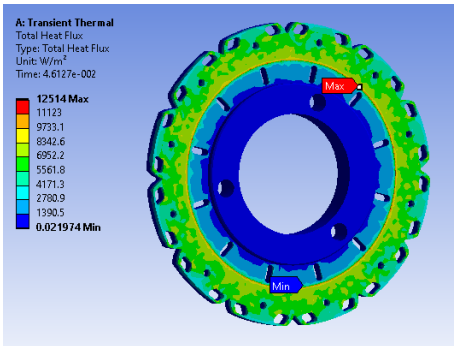


Fig. 38 – Heat flow values for ceramic.

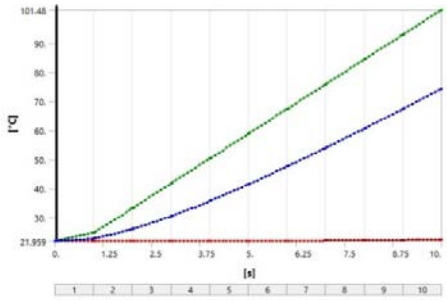


Fig. 39 – Resulted stats for temperature parameter- ceramic material.

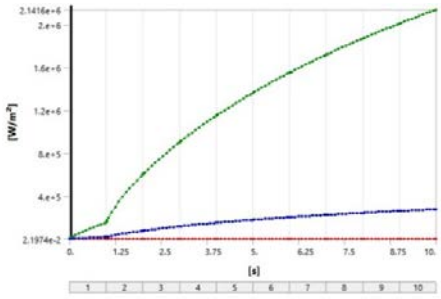


Fig. 40 – Resulted stats for heat flow parameter- ceramic material.

From the analysis values, an improvement of the accumulated temperature values is visible, better than the other materials used previously. The results obtained from thermal analysis show a maximum temperature of *101.48°C*, on the contact zone of the brake disc for the ceramic material type, presented in Figs. 37 and 38.

Comparing the heat flow value to cast-iron analysis, Figs. 39 and 40 show a lower value for heat flow, *2.1416e+6* for ceramic material.

Also, ceramic can be more reliable in a wider range of temperature.

4. Conclusions

Starting from its main role and moving on to the importance of the braking system, whether it is a car, a motorcycle or any other type of vehicle, a thermal analysis was needed for the thermal behaviour of the disc. The brake discs under analysis are in the category of light vehicles, which are not tested at high demands and the force value is much lower than for a car. The main intention was to improve the quality of use for this tricycle and to reduce the temperature values for the braking system.

The thermal results that were achieved, for the beginning only a number of five design variants for discs, showed that variant 3 is the most efficient in terms of thermal and thermal requirements and variant number 4 has the lowest thermal efficiency. For the second set of thermal analysis, in which the material used for the brake discs was modified, it resulted that the ceramic material had the best behavior following the sustained thermal analysis, due to its properties, decreases the temperature on the surface of the disc for the same stress, compared to the other materials used.

It was necessary to carry out a thermal analysis, with change of materials, because in the last decades the technology has advanced a lot and allowed the use of several types of materials for the construction of brake discs. Thus, three different types of materials were used to have a wider range of

selection. This selection of material, to which was added an improved version of the disc model, created an improved scenario for the braking system from a thermal point of view.

REFERENCES

Chetan B.C., Anurag S.M., Nikhil N.P., Baskar P., *Static Structural and Thermal Analysis of Brake Disc with Different Cut Patterns*, Journal of applied research and technology, 2018, **16**(1), 41-52.

Gongyu P., Rongyu C., *Thermal Stress Coupling Analysis of Ventilated Disc Brake Based on Moving Heat Source*, Advances in Materials Science and Engineering, 2018, **2018**(5), 1-11.

Manthan V., Balbir S., *Experimental and Numerical Thermal Analysis of Formula Student Racing Car Disc Brake Design*, Journal of Engineering Science and Technology Review, 2018, **10**(1), 138-147.

Metha I., Christopher F.K., Bentang A.B., *Influence of Braking Strategies for Electric Trike Energy Consumption*, International Journal of Sustainable Transportation Technology, 2020, **3**(1) 20-25.

Pinca-Bretotean C., Preda C., Josan A., *Numerical and Experimental Analysis of Dry Contact in Pad Disc Brake Assembly*, IOP Conf. Ser.: Mater. Sci. Eng, 2020, **1426**, 012002.

Sharath K.M., Junling H., *Study on Transient Thermal Analysis of a Disc Brake During Braking and Releasing Periods*, ASEE Northeast Section Conference, 2017, Massachusetts, USA, April 27-29.

Siddharth S., Rahul S.R., Mohd Z.F., Mohd S.F., Mohd S., Omprakash S., *NFC Enabled Drift Trike*, 3rd International Conference on New Horizons in Science, Engineering and Management and Humanities, 2019, Greater Noida, India, April 19th.

Vikas V., Chauhan S.S., Kumar R., *Design & Development of Combined Human and Electric Powered Vehicle*, International Journal of Advance Engineering and Research Development, 2016, **3**(4), 43-50.

Vishal F., Gajanan J., Ramachandran M., *Design, Modelling and Analysis of Tilted Human*, International Conference on Mechanical, Materials and Renewable Energy, 2018, Amsterdam, Netherlands, May 16-17.

MODELAREA ŞI ANALIZA COMPORTAMENTULUI TERMIC PENTRU DISCURILE DE FRÂNĂ

(Rezumat)

Referindu-ne strict la sistemul de frânare, acesta este unul dintre cele mai importante componente pentru orice tip de vehicul, fie că vorbim de autovehicule,

motociclete sau biciclete. Rolul său principal este de a converti energia cinetică și potențială a vehiculului în căldură, ceea ce îi permite acestuia să oprească.

Scopul acestei lucrări este de a concepe și a analiza cinci variante posibile ale geometriei discului de frână, fiecare geometrie fiind diferită de cealaltă. Pentru că pentru o degajare mai eficientă a căldurii și a fluxului de căldură, cele cinci geometrii alese ale discurilor prezintă pe suprafața acestora orificii și prelucrări, canale de aerisire, pentru a elimina cât mai eficient căldura de pe suprafața lor, în momentul în care sunt solicitate la tensiuni termice. Pentru realizarea propriu-zisă a discurilor, modelele alese au fost realizate și proiectate în programul de proiectare CATIA V5.

Următorul pas în această lucrare a fost efectuarea de analize și simulări pentru discurile selectate. Totodată, a fost luat în considerare materialul ales pentru acestea. Modelele 3D au fost importate în programul de analiză ANSYS, unde s-au efectuat analize individuale pentru fiecare disc de frână și s-a făcut o comparație între valorile fiecăruia.