THERMAL ANALYSIS OF BRAKE DISC

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ABSTRACT

This study explores the comparative performance of brake discs with and without perforations, focusing on their thermal management, durability, and overall efficacy under varying operational stresses. Perforated or drilled brake discs are known to offer enhanced heat dissipation due to their increased surface area and improved airflow, which helps in reducing the temperature during heavy braking and prevents brake fade. This feature makes them particularly suitable for high-performance vehicles where braking systems are subjected to intense and prolonged use.

Conversely, solid brake discs, which lack perforations, typically exhibit greater durability and a longer lifespan, making them ideal for standard driving conditions. Their robust nature ensures consistent performance and reduced susceptibility to thermal stress-induced failures such as cracking.

This paper analyzes both types of discs through experimental setups involving thermal and stress simulations, as well as real-world operational testing. The findings aim to provide a comprehensive understanding of how the structural differences between perforated and solid brake discs influence vehicle performance, safety, and maintenance needs, facilitating informed decisions regarding brake disc selection based on specific vehicle requirements and usage patterns.

This study conducts a detailed examination and optimization of rotor disc designs using CREO Parametric for design modeling and ANSYS Workbench for simulation analysis. The primary focus is to compare the thermal and structural performance of perforated and solid rotor discs under simulated and real-world conditions. Using experimentally validated methods, the

research tests various rotor configurations to determine their efficiency in heat dissipation and resistance to vibrational stress.
Optimization techniques are applied to enhance the geometric and material properties of the rotor discs, aiming to identify the best configuration that meets performance and durability criteria. The findings are expected to guide the design choices in automotive and aerospace applications where rotor disc performance is critical. This comprehensive approach ensures that the optimized rotor disc designs are not only theoretically sound but also practically viable in operational environments.

Keywords: CREO Parametric, ANSYS Workbench, Experimentally Validated, Optimization, Rotor Disc

1. INTRODUCTION

● The brakes must have good anti-fade characteristics i.e. their Effectiveness should not decrease with constant prolonged application

● Brake should possess good anti-wear properties

1.2 BRIEF HISTORY OF DISC BRAKES:

The development of disc brakes first began in England in the 1890s. First calliper-type automobile disc brake patented by Frederick William Lanchester in 1902 and used successfully on Lanchester cars. Due to limited choice of metals at that time, he used copper in making brake pads. But the poor state of the roads (dusty and rough) caused the copper wore quickly, making the disc brake system unfeasible. Reliable calliper-type disc brakes first appeared in 1953 on the Jaguar C-Type racing car. These were developed in the UK by Dunlop. In 1953, the aluminium bodied Austin-Healey 100S, was the first car sold to the public to have disc brakes. They were fitted to all 4 wheels. The first mass production use of the modern disc brake was in 1955, on the Citroën DS, which featured calliper-type front disc brakes among its many innovations. These discs were mounted inboard near the transmission, and were powered by the vehicle's central hydraulic system. Brake discs were manufactured throughout the world with a strong concentration in Europe and America. Between 1989 and 2005, manufacturing of brake discs migrated predominantly to China

1.3 CLASSIFICATION OF MECHANICAL BRAKES:

The mechanical brakes according to the direction of the acting force may be divided into:

Radial Brake

In these brakes the force acting on the brake drum is in radial direction. The radial brakes may be subdivided into external and internal brakes.

Axial Brake Brake Pads
Callipers containing pistons
Rotor Disc mounted on Hub

In these brakes the force acting on the brake drum is only in the axial direction viz. Disc Brakes, Cone Brakes etc.

1.3.1 DISC BRAKE:

A disc brake usually consists of a Cast Iron Disc bolted to the wheel Hub and a stationary housing called calliper. The calliper is connected to the same stationary part of the vehicle like the axial casing or the Stub Axle as is cast in two parts each part containing a piston. In between each piston and the disc there is friction pad held in position by retaining pins, spring plates etc. Passages are drilled in the calliper for the fluid to enter or leave the housing. The passages are also connected another one for bleeding. Each cylinder contains a rubber sealing rings between a cylinder and piston.

The main components of the Disc Brake are:

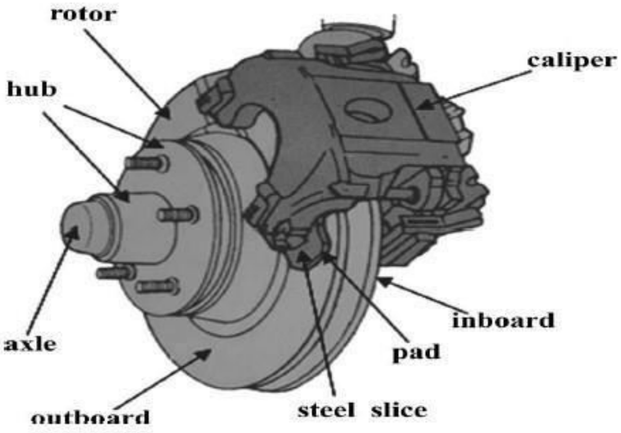


Fig 1 Disk Brake

When the brakes are applied, hydraulically actuated pistons move the friction pads to contact with the rotating disc, applying equal and opposite forces on the disc. Due to friction in between disc and pad surfaces, kinetic energy of the rotor is converted into heat, by which the vehicle is to stop after a certain distance. On releasing the brakes, the brakes, rubber sealing rings act like return springs and retract the piston and the friction pads away from the disc.

1.3.2 TYPES OF CALLIPERS:

Floating callipers move in and out relative to the rotor and have one or two pistons only on the inboard side of the rotor. This piston pushes the entire calliper when the brakes are applied, creating friction from the brake pads on both sides of the rotor.

Fixed callipers, as the name implies, don't move, but rather have pistons arranged on opposing sides of the rotor. Fixed callipers are generally preferred for their performance, but are more expensive than the floating kind. Some high-performance fixed callipers have two or more pairs of pistons (or "pots") arranged on each side of the rotor some have as many as six pairs total.

1.4.Problem Identification

The calliper pistons exert pressure on the rotor disc and the temperature of the rotor disc increases. Temperature increase leads to thermo-elastic expansion of the rotor. There is localised expansion causing formation of hot spots. This causes vibration in the axial direction. The coefficient of friction is a function of sliding velocity and time. With time, more heat is generated in the rotor. According to Stribeck Curve the coefficient of friction decreases with increase in sliding velocity. This repeatedly over time leads to fading of brake pads. Moreover, the tangential vibration causes sinusoidal variation of the heat flux. When the pads vibrate in the sense of rotation of the rotor friction is reduced and heat is lowered and vice-versa.

2. LITERATURE SURVEY

In order to study the couple thermal-structural analysis of the disc brakes, the literature regarding the above has been studied. The following section details the literature available and relevant to the proposed study of thermal-structural analysis of the rotor disc.

Faramarz Talati et al [1] extracted the governing heat equations for the disc and the pad in the form of transient heat equations with heat generation that is dependent on time and space. The paper depicted that the heat generated due to friction between the disk and the pad should be ideally dissipated to the environment to avoid decrease of the friction coefficient between the disk and the pad, to avoid the temperature rise of various brake components and brake fluid vaporization due to excessive heating. The difference between the surface temperature of the disc and the pad is relatively high i.e. for the braking time of 3.96 sec, 950 0C at the pad surface and 300 0C at the disc surface. The results obtained for contact surface temperatures of the pad and the disk reveal that there is a heat partition between two components in sliding contact, because of thermal resistance constituted by accumulation of wear particles at the contact surface between the pad and the disk that forms a thin layer. It presented a provision to remove wear particles from contact zone of sliding components of which one is to contrive slots on the surface of the pad. This thermal resistance between the pad and the disk prevent the disk from absorbing the generated heat at the contact surface of the pad, so that temperature of the pad increases and consequently heat soaking to brake fluid increases and this may cause brake fluid vaporization. Therefore, another provision that should be taken into account is to use a brake fluid with an appropriate DOT rating. **J Hari Narayana Rao et al** [2], performed coupled field Thermal- Structural analysis on the rotor disc incorporating different materials of the rotor disc viz. Cast Iron, Stainless Steel and Aluminium alloy. The work includes a comparison between an actual solid disc and varied design discs by cross drilling holes in the rotor disc for more heat dissipation.

The paper concludes that the cross drilled rotor can offer more heat transfer and less weight. Thus, the design of brake system is studied and some model calculations of disc brake and analysis of solid and cross drilled rotor for three different material have been done. The design shows the various modifications that can be done in rotor to help them create more friction as well as disperse heat more quickly. Observing the structural analysis revealed that for the displacement criterion the aluminium perforated disc has more displacement when compared to solid disc of same material whereas the stress analysis showed the steel perforated disc withstands to more stress when compared to solid disc of same type. On the other hand, from the results of thermal analysis it is observed that the amount of temperature produced in the cast iron perforated disc is 187 K lesser than the temperature produced in solid disc of same type as well as the thermal flux criterion too favoured the aluminium perforated disc giving more heat dissipation per unit area compared to solid disc of same type. Considering the above the aluminium perforated disc was proposed as best.

A.Belhocine and M. Bouchetara [3] analysed the thermal behaviour of the full and ventilated brake discs of the vehicles using computing code ANSYS. The modelling of the temperature distribution in the disc brake was done to identify all the factors and the entering parameters concerned at the time of the braking operation, such as the type of braking, the geometric design of the disc and the material used.

Dr Sanjay Chikalthankar et al [4] prepared solid model in ProE then model was taken to Hypermesh software for meshing. ANSYS was used for vibration analysis in which the natural frequency of the component was found. The vibration analysis is done to find out the maximum displacement of the component about the different axes. The validation was done with an experimental setup.

Prashant Sharma et al [5] have presented an analytical model for the determination of the contact temperature distribution on the working surface of a brake. To investigate the temperature distribution for the rotor disc used by two-wheelers in India a comparison was made between two different discs of same materials and of same dimensions, the only difference that one is perforated. The main module used in this work is transient thermal analysis where the temperature distribution at different time intervals is determined. Convection as well as radiation boundary conditions were simultaneously applied on both the rotor models. The initial condition assumed here is that the vehicle has stopped completely by application of brakes. The analysis of both the models was done and observing the results stated that in spite of holes present in the perforated model, the minimum temperature attained by both the bodies after specific time instant turned out to be almost equal but the temperature distribution in perforated model is much better as there is less temperature difference compared to simple disc. Hence, the perforated rotor model is better regarding heat dissipation as compared to the simple solid rotor disc.

Manjunath T V and **Dr Suresh P M** [6] performed coupled thermal- structural analysis to determine the deformation and the Von Mises stress established in the disc for the both solid and ventilated disc with two different materials to enhance performance of the rotor disc. A transient thermal analysis was carried out to investigate the temperature variation across the both disc by applying heat flux value for repeated braking applications. Further structural analysis is carried out by coupling thermal analysis. A comparison between analytical results obtained from FEM is done of solid discs and ventilated discs to validate the results. The paper concluded that ventilated type disk brake is the better for the present application than the former one because the comparison results of temperature rise, deflection, and stress field obtained from analysis revealed that in the ventilated cast iron disc reduction in temperature, stresses and deformation is by 31.47% , 22.5% and 8% respectively than the solid disc.

Yathish K.O et al [7] tried to propose an alternative for conventional materials with the composites to reduce the weight of rotor disc. The performance of rotor disc for different materials like Cast iron & Aluminium6061-SiC-red mud composite was analysed under same working conditions. And the material impact on displacement, stress, contact pressure, contact status, contact sliding distance of disc and pad assembly are obtained using software packages like ANSYS (14.5) and Hypermesh. Aluminium based metal matrix composite (MMC) was found to be the best alternative.

Viraj Vijaykumar Shinde et al [8] performed structural & thermal analysis of two different cut patterns of brake disc to study heat transfer rate. The heat transfer rate increases with number of cuts in the disc since large area is exposed to air resulting in more heat transfer through conduction and convection. But contrary, increase in number and size of cuts leads to relative reduction in the strength of disc. Mechanical modelling is done for two different cut patterns by taking average dimensions of two wheeler brake disc. Further these models were imported in ANSYS for thermal and structural analysis. For thermal analysis, temperature contours depicted that circular type cut pattern disc showed dense red coloured contours near cuts while for elliptical type of cuts less dense red colour region was displayed since the air circulation through cuts was found better in it. Also the velocity vectors analysis meant heated air in elliptical cuts leaves the space and allows fresh air to come in contact with cut surfaces of disc and carry the heat from disc. This phenomenon for circular cuts take place on lower scale. This paper concluded that the elliptical type of cut pattern has better heat transfer than the other one whereas the structural analysis concluded that elliptical type cut pattern is weaker to withstand braking forces when compared to circular type of cut pattern since the deformation and Von-Mises stress analysis turned out to possess a higher value for the former type.

Chetan T. Jadav and **K. R. Gawande** [9] performed an analysis of disk brake of Bajaj Pulsar 150cc. The cost of disc rotor of pulsar was found around

₹ 900 and that of friction pad around ₹ 150. By keeping the braking torque constant, reducing the diameter of disc rotor and increasing the friction pad area the cost and weight of disc assembly were reduced by 28% and 44% respectively. **P.K. Zaware et al** [10] modelled three rotor discs in Pro-E and using ANSYS software finite element method was applied to find the Total Deformation, Von-Mises Stress Distribution and Steady State Thermal Analysis of the rotor disc of Baja Pulsar 150 and three other modified discs was done. After comparison the Modified Shape 2 disc was found optimum which was later experimentally validated. The temperature of the rotor disc was measured by infrared sensor, projecting laser beam on region-wise diameter of disc brake rotor of original & modified shape 2 disc brake rotor.

Sreekanth Reddy S et al [11] modelled a disc brake in CATIA and did stress analysis in ANSYS workbench for the different Aluminium, Grey Cast Iron, HSS M42, and HSS M2. From the comparison among the four materials of the material properties, stress strain and displacement values obtained from the structural analysis, material in which low stress is induced was Aluminium.

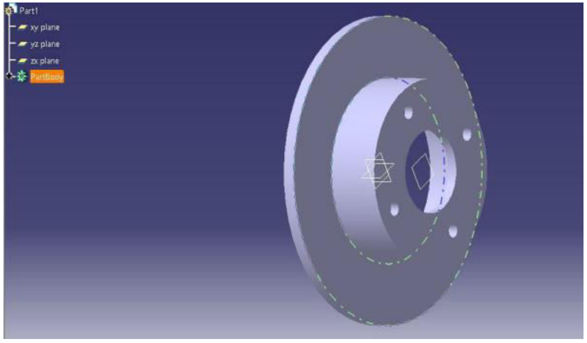
3. PROPOSED SYSTEM

Design of DISC BRAKE ROTOR

3.1.Sketch and development of 3D Model

TABLE 3.1

Parameter	Normal disc (mm)	Drilled disc (mm)
Inner Dia.	60	60
Outer Dia.	221	221
Hub Dia.	133	133
Disc Thickness	10	10
Hole dia.	10	6
Hub Length	45	45



3.2 ASSIGNING MATERIAL

As describe in literature survey the material for rotor disc are Grey Cast Iron (ASME A40), Stainless Steel, Titanium. Among them Grey Cast iron is the cheaper as well as generally used material for rotor disc. In Software Grey Cast iron material is developed with properties as shown in table.

TABLE 3.2

Properties	Grey C.I.	S.S.
Density (Kg/m^3)	7100	7743
Poisson's Ratio	0.218	0.3
Young's Modules (Gpa)	110	193.053
Tensile Yield Strength (Mpa)	276	215
Tensile Ultimate Strength (Mpa)	430	505
Compressive Ultimate Strength (Mpa)	890	-
Specific Heat Capacity (J/Kg K)	450	400.412
Thermal Conductivity (W/ m K)	46	14.039

3.3.GENERATE STEP FILE (.STP)

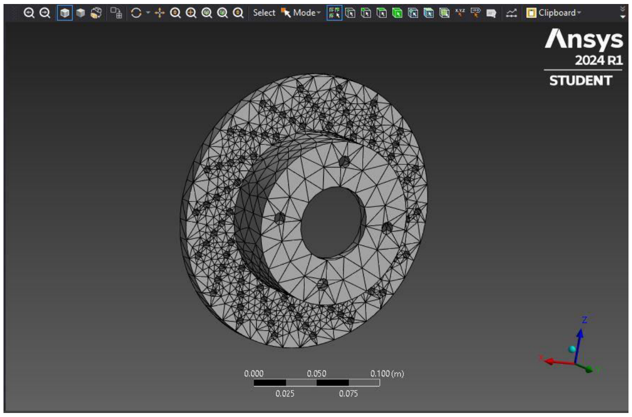
For the analysis purpose file must be converted into STEP file which include all surfaces, geometry, Axis, points. STEP file can be understood by ANSYS analysis software.

3.4 OBTAINING SOLUTION

3.4.1 CREATING FINITE ELEMENT MESH

In Ansys (student version) Modal Mashing was created and get the number of triangular shape element.

Hear data for both normal and drilled
Accuracy: High
Course: Fine
No. of Element: 30142 No. of Nodes: 52190



Static Structural Analysis

3.4.2 PERFORMING ANALYSIS

After Meshing following analysis are to be performed

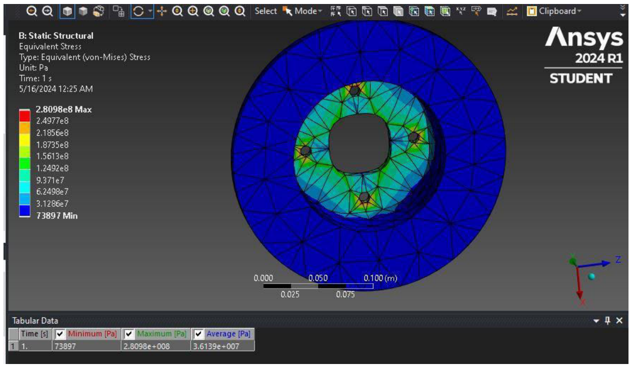
In this analysis we applied breaking pressure at the one surface and we got two output

1) Equivalent Stress (von-Mises)
2) Total Deformation Transient thermal analysis

In this analysis breaking pressure is applied with boundary condition like ambient temperature (22˚C), convective heat transfer coefficient (90 W/m2 K) on the basis of Assumption. Output from this analysis are,

1) Temperature
2) Total heat flux

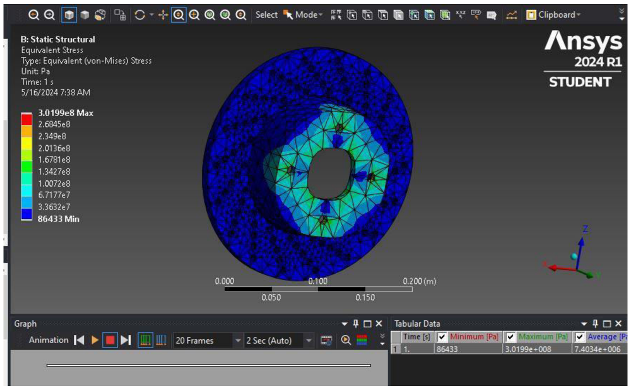
3.4.3 STATIC STRUCTURAL ANALYSIS



B: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: Pa
Time: 1 s
5/16/2024 12:25 AM

Tabular Data

	Time [s]	☑ Minimum [Pa]	☑ Maximum [Pa]	☑ Average [Pa]
1	1.	73897	2.8098e+008	3.6139e+007



B: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: Pa
Time: 1 s
5/16/2024 7:38 AM

Tabular Data

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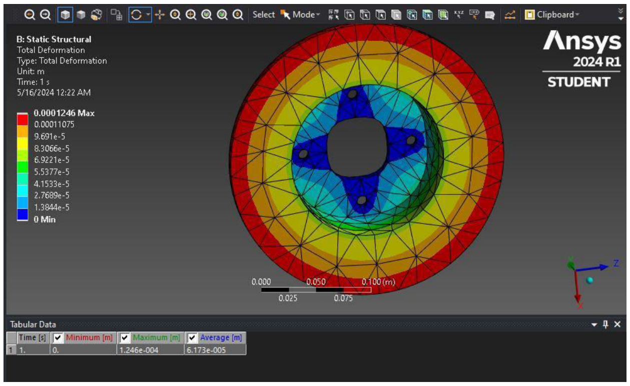
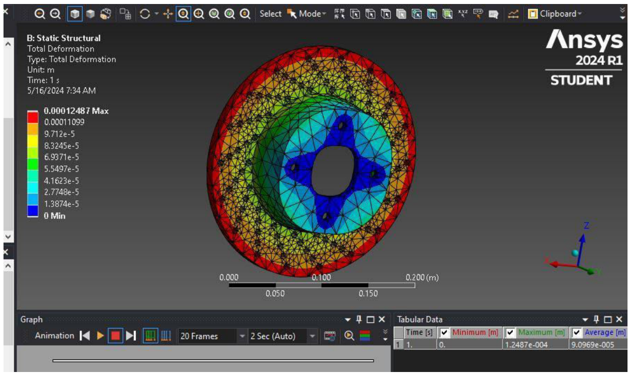


B: Static Structural
Total Deformation
Type: Total Deformation
Unit: m
Time: 1 s
5/16/2024 12:22 AM

Tabular Data

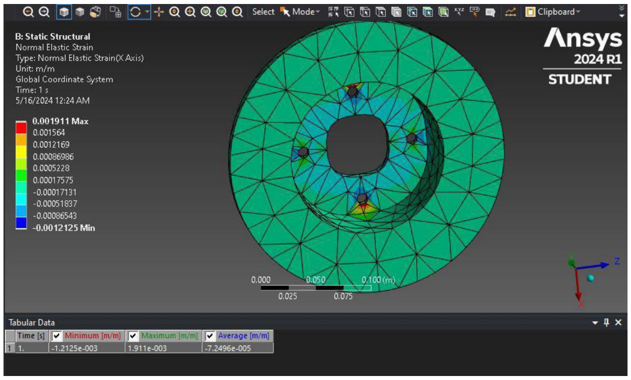
	Time [s]	☑ Minimum [m]	☑ Maximum [m]	☑ Average [m]
1	1.	0.	1.246e-004	6.173e-005



B: Static Structural
Total Deformation
Type: Total Deformation
Unit: m
Time: 1 s
5/16/2024 7:34 AM

Tabular Data

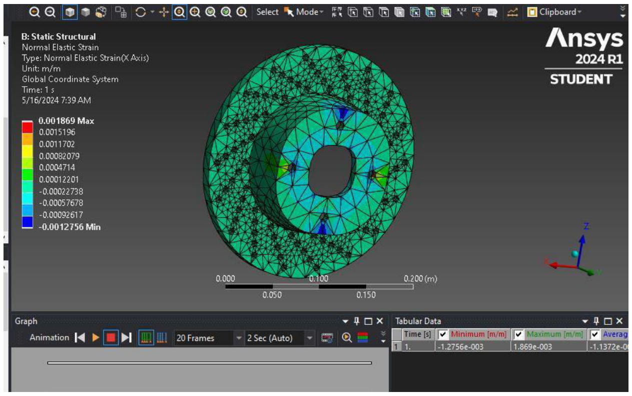
	Time [s]	☑ Minimum [m]	☑ Maximum [m]	☑ Average [m]
1	1.	0.	1.2487e-004	9.0969e-005



B: Static Structural
Normal Elastic Strain
Type: Normal Elastic Strain(X Axis)
Unit: m/m
Global Coordinate System
Time: 1 s
5/16/2024 12:24 AM

Tabular Data

	Time [s]	☑ Minimum [m/m]	☑ Maximum [m/m]	☑ Average [m/m]
1	1.	-1.2125e-003	1.911e-003	-7.2496e-005


B: Static Structural
Normal Elastic Strain
Type: Normal Elastic Strain(X Axis)
Unit: m/m
Global Coordinate System
Time: 1 s
5/16/2024 7:39 AM

Tabular Data

Time [s]	☑ Minimum [m/m]	☑ Maximum [m/m]	☑ Averag
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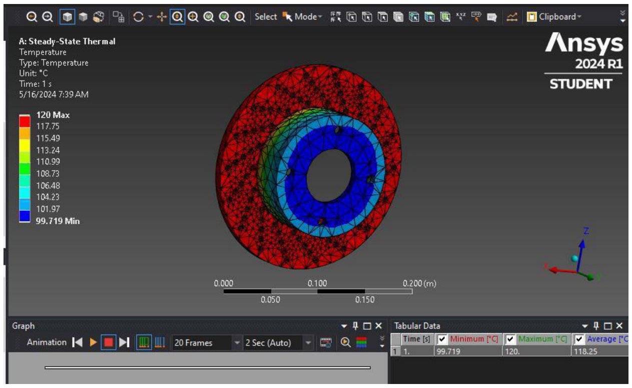
A: Steady-State Thermal
Temperature
Type: Temperature
Unit: °C
Time: 1 s
5/16/2024 7:39 AM

Tabular Data

Time [s]	☑ Minimum [°C]	☑ Maximum [°C]	☑ Average [°C
1.	99.719	120.	118.25

4. RESULTS

Structural Analysis

Equivalent stress

TABLE 4.3

Disc	Max (Mpa)	Min(Mpa)
Normal	2.809	0.00073897
Drilled	3.3011	7.8228e-6

Total Deformation

Temperature distribution

TABLE 4.5

Disc	Max (˚C)	Min (˚C)
Normal	120.02	24
Drilled	120	22.1

Temperature distribution

TABLE 4.5

Disc	Max (˚C)	Min (˚C)
Normal	120.02	24
Drilled	120	22.1

Total Heat Flux

TABLE 4.6

Disc	Max (W/mm$^{2)}$	Min (W/mm^2)
Normal	3.1074	2.329e-11
Drilled	3.4310	5.1478-11

5. CONCLUSION

In conclusion, the analysis of brake discs with and without holes has provided valuable insights into their performance characteristics under operational stress. Brake discs with holes, commonly known as perforated or drilled brake discs, exhibit enhanced heat dissipation capabilities compared to their solid counterparts. This results from increased surface area and improved airflow, which collectively aid in 46

reducing the brake temperatures during intense or prolonged use. This temperature reduction is crucial in preventing brake fade and maintaining braking efficiency.

Furthermore, perforated discs are often lighter in weight, which can contribute to a slight decrease in the unsprung mass of a vehicle, potentially enhancing handling dynamics. However, these discs can also be more susceptible to stress fractures under certain conditions due to the presence of holes.

On the other hand, solid brake discs, without holes, tend to have a longer lifespan and are generally more durable under normal driving conditions. They provide consistent performance for everyday use and are less prone to cracking under high thermal stress.

Ultimately, the choice between perforated and solid brake discs should be guided by the specific requirements of the vehicle and the driving conditions it will encounter. Perforated discs are ideally suited for high-performance applications where heat dissipation is a priority, while solid discs offer reliability and durability for regular driving.

Future Scope:

The primary factors reducing the lifespan of a rotor disc are vibration and heat generated from thermo-elastic expansions. To mitigate these issues, enhancing heat dissipation is crucial. This will involve a detailed analysis of the rotor's dynamic conditions, determining the temperature distribution, and calculating the total heat flux produced. By comparing the performance of plain disc rotors and perforated disc rotors in terms of temperature distribution and heat dissipation, we can identify the optimal design. Using these insights, new rotor disc designs will be developed and analyzed to propose the most effective solution for improved thermal management and durability.

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