Thermal and Analytical Validation of Disc Brake Rotor with Plain and Crossed Drilled Holes

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Abstract— **the ventilated brake disk is the cutting-edge technology in automotive braking systems. Brake disk performance is known to be impacted by the rate at which heat is released by forced convection. Significant heat stress from the brake disk's rapid rise and fall could cause a catastrophic breakdown. By changing the geometrical properties of cross-drilled holes, the current study seeks to assess the possible increases in heat transmission in vented brake disks. Nearly 26 kg of the wheel assembly's weight is attributed to the brake rotor. While most research focuses on changing the brake rotor's material, not much has been done to enhance its design without sacrificing performance. Additionally, the study offers a method for lowering the weight of drilled type braking rotors without sacrificing or significantly lowering performance. We built a standard drilled cast iron brake rotor for this project and conducted structural and thermal analyses. Topology, which involved analysing the unwanted material that could be removed without affecting the rotor's performance, was conducted using the results that were obtained.**

Keywords: **ANSYS, FEA, Heat Transfer Co-efficient, Heat flux Thermal analysis, Ventilated disc brake.**

INTRODUCTION

A brake is a device that slows down and stops a moving mechanical wheel by applying frictional retardation. In this operation, the disc brake's rotor absorbs the mechanical wheel's rotational motion.Heat is released as a result of the disc rotor's absorption of energy. The disc rotor dissipates this heat into the surrounding and adjacent disc assembly locations. A disc brake slows down the mechanical wheel's movement to lower its speed and stop it by using a pair of calipers with friction pad material to apply friction on the rotor.

To avoid overheating the brake pads and disc, which could lead to failure, the energy of slowing motion is converted into thermal energy and released into the environment. Usually, gray cast iron, a type of cast iron, is utilized. The discs, which are often made by the casting technique, come in a variety of construction kinds, such as solid, drilled with many pattern holes, etc. The vented disc rotor must be implemented due to the dynamics of the vehicle's driving behavior and statistics. The "ventilated" disc design, which is frequently found on the front side disc brakes of big motor vehicles and luxury cars, aids in the quicker and simpler discharge of heat generated.

These days, vented disc brake rotors are found in many vehicles, including motorcycles and bicycles. Effective heat dissipation, improved performance to support improved traction, peripheral fluid distribution, noise reduction, and disc brake rotor weight reduction are the reasons for this.

LITERATURE REVIEW

Cosmin Preda (1) examined the tribological and mechanical properties of different compositions of aluminum 6063 alloy-clay (Al-clay) composites used in brake pad applications. Stir casting was used to create the Al-clay composites, which had 5–30 weight percent clay particles with a grain size of 60 BSS (250 microns). A series of Denison T62 HS pin-on-disc wear experiments were used to evaluate the wear properties of Al-clay in dry sliding conditions. Three sliding speeds of 200, 500, and 1000 rpm were examined, as well as the effects of two distinct weights (4 and 10 N) Tensile strength, hardness, and wear resistance were all improved in the composites containing 10–25 weight percent clay, according to the findings of mechanical and wear tests as well as metallographic analysis using optical, scanning electron, and energy dispersive X-ray microscopy. At 15 weight percent, the best results were attained. Both sliding speed and applied load have a significant impact on wear rate. In terms of wear and friction characteristics, the created composites with a 15–25% clay addition were comparable to traditional semi-metallic brake pads. David Hesse, et al (2) A paper titled "Testing of

Alternative Disc Brakes and Friction Materials Regarding Brake Wear" was published by MDPI in 2021. This study evaluates the particle emission output of several disc brakes and friction materials and derives typical features. Using a constant volume sampling system, the measurements are made on an inertia dynamometer. A grey cast iron disc, a disc coated with tungsten carbide, and a carbon ceramic disc are used to calculate and compare the brake wear particle emission factors of several disc designs in various sizes. The brakes underwent testing during a new test cycle (trip #10) that was created using the database of the globally harmonized Light-Duty Vehicles Test Procedure (WLTP). First, a series of trip-10 tests were used to evaluate brake emission variables along the bedding process. Deekshith Ch (9) This paper conducted a thermal and structural investigation of a vehicle's disc brake rotor. Analysis was done on the disc brake rotor's heat generation and dissipation. By varying the thickness and material, additional analysis was done to verify the heat flux and temperature distribution. In the research project, two materials—gray cast iron and stainless steel—and two thicknesses—5 and 6 mm—were taken into consideration for investigation. The disc brake rotor was analyzed using ANSYS 15.0 and designed using CATIA V5R20. Comparing the heat flux and temperature distribution of disc brake rotors made of two distinct materials was the aim of this study. Following the analysis of the results, a CNC machine was used to manufacture the rotor for optimal performance.

PROBLEM DEFINITION:

In a car brake system, a comparison between a plain disk rotor and one with drilled holes. A car's braking system is an essential safety feature, and the brake rotor is essential for distributing heat and guaranteeing effective braking. The two main types of brake rotors are drilled hole disk rotors and plain disk rotors. Every design has distinct structural and functional features that affect things like heat dissipation, braking effectiveness, durability, and upkeep. To make wise design and material decisions, it is necessary to fully comprehend the performance trade-offs. Although plain disk rotors are easy to manufacture and have strong structural integrity, their cooling efficiency may be lower than that of drilled variants. Conversely, rotors with drilled holes are made to dissipate heat more effectively and weigh less, but they may have problems including cracking, stress concentration, and a shorter lifespan under high stress conditions.

OBJECTIVE

Heat Transfer Enhancement: The primary goal is to improve the heat dissipation rate of ventilated brake disks. By optimizing the geometrical features of the drilled holes, the study aims to maximize forced convection, which would allow the brake disk to cool more efficiently during and after braking.

Minimizing Thermal Stress: The rapid fluctuations in brake disk temperatures, particularly during high-performance braking, can lead to thermal stresses that cause cracks, warping, or failure of the brake disk. The study seeks to minimize these risks by improving thermal management.

Design Modification without Sacrificing Performance: While much research has focused on changing materials (e.g., carbon composites, ceramics), this study explores a more cost-effective approach by optimizing the design of the existing brake rotor, specifically through the geometry of drilled holes. The goal is to reduce the rotor's weight without compromising the braking performance, or with minimal performance degradation.

Weight Reduction: Brake rotors contribute significantly (approximately 26 kg) to the weight of the wheel assembly. A lighter rotor would improve vehicle efficiency, handling, and fuel economy. The study suggests that the weight of the drilled-type brake rotor can be reduced through careful design modifications without negatively affecting the performance or safety of the braking system.

METHODOLOGY

The process for the best design is described below. To set the boundary conditions prior to the study, the target vehicle's initial state was ascertained. It was supposed that all of the kinetic energy of the moving vehicle is transformed into thermal energy by friction between the brake disc and the pad during braking, and that the input pressure of the pad creates a pressure distribution in the areas of the disc and the pad in contact with one another. In the initial state, structural and thermal evaluations were carried out.

1. Initial Conditions

- Mass of the Vehicle

- Initial Velocity
- Time to Stop

2. Boundary Condition Calculations
- Structural Analysis
- Thermal Analysis

3. Design Progress
4. Experimental Setup for Validation
5. Documentation of Results

DESIGN OF THE DISC ROTOR

To design a disc brake considering a standard light vehicle to fulfil the following purposes:

- Locking of the wheels of the vehicle at the instant of braking.
- Effective brake force distribution.
- Minimization of weight of total braking system.
- To reduce unsprung mass.
- Better response and handling.

1. A standard Maruti Suzuki Wagon R is considered and the different parameters selected.
2. The dynamic weight transfer during braking on the front and rear axle is 60:40 percent of the total vehicle weight respectively.
3. All the four wheels will come to rest when brakes are applied and the condition of slip is also considered.
4. The kinetic energy of vehicle is dissipated in the form of thermal energy.
5. Ambient temperature is assumed to be constant at 27˚C and the convection and radiation is taking place through air.
6. The thermal conductivity of material is uniform throughout the process.

Sr.No	Parameters	Values
1	Pedal ratio $(L_2/\, L_1)\, L_P$	6:2:1
2	Bore diameter of master cylinder (b_{mc})	28 mm
3	Caliper piston diameter (b_p)	54 mm
4	Velocity of Vehicle (V_v)	120 Kmph =33.33m/s
5	Constant deceleration while braking	9.09 m/s^2
6	Weight of vehicle (W)	1340 kg
7	Tire slip (s)	0.07
8	Outer effective Diameter of Brake Disc(D)	230 mm
9	Inner effective Diameter of Brake Disc(d)	142 mm
10	Pedal lever efficiency (n_ρ)	0.8
11	Initial mass of rotor (m_d)	6.98 kg
12	Material	Gray Cast Iron
13	Specific heat of Cast Iron (C_P)	462 J/kg.K
14	Room ambient Temperature (t_{intial})	27^0C
15	Density of Cast iron	7200 kg/m^3
16	Young's Modulus of Cast Iron	125 GPa
17	Thermal Conductivity of Cast Iron	52 W/mK
18	Height	52.6mm
19	Minimum Thickness	8.2 mm
20	Number of Vanes	32
21	Diameter of Tire	28 in
22	Nominal Thickness	23.8 mm

Table 1: Vehicle and Brake Rotor Specification

Numerical Calculation for Ventilated Disk rotor

1. Mass of Vehicle (m) = 1340 kg.
2. Top Speed (v) - 120 km/hr = 33.33m/s.
3. Coefficient of Friction(μ)= 0.41.
4. Youngs Modulus = 125 GPA.
5. Density = 7200.kgm^3
6. Thermal Conductivity = 52w/mk
7. Room Ambient Temperature (Ti) = 27°c=300k.
8. Poisans Ratio = 0.28
9. Coefficient of Thermal Expansion (CTE) = 8.1x10^{-6}

1. Kinetic Energy (KE)

KE = ½ mv^2

=1/2 (1340) x $(33.33)^2$=744.29x10^3J

2. Stopping Distance (Friction Force Method)

- Friction Force=μ x w

  =μ x m x g

  =0.41 x 1340 x 981

  =5389.6
- ·Deceleration (a):= (F/M) = $\left(\frac{5389.6}{1340}\right)$

  a= 4.022 m/s^2
- Time to Stop (t):= $\frac{v}{a}$ = $\left(\frac{33.33}{4.022}\right)$

  t= 8.285
- Stopping Distance (s):= (v x t)

  = 33.33 x 8.28

= 275 m

Stopping distance based on reaction time of drivers.

SD = (V x t) + $\left(\frac{v^2}{2\,\mu g}\right)$

= (33.3 x 3.33) + $\left(\frac{33.3^2}{2\times0.41\times9.81}\right)$

=110.8 + 137.8

= 248.6 m

Braking Force = $\frac{KE}{SD}$

= $\frac{74428\times10^3}{248.6}$

= 2993.8 N

Power = (KE / T)

= $\left(\frac{744.29\times10^3}{8.28}\right)$

BP = 89.890 kW

Since 60% of Mass on Front

Power on Front Wheel = (89.890 X 0.6)

= 53.934 KW

Power on Each Front Wheel = $\frac{53.934}{2}$ = (26.967 kW)

3. Torque and Speed Calculations:

B. Power = (T X W) = $\frac{2\,Tin}{60}$ x T

Where N - ? W = 111.rad/S

V = πDN

Rotational Speed (N)= $\frac{v}{\pi\,D}$

= $\left(\frac{33.33}{\pi\times0.6}\right)$

N = 17.68 rps

N = 1060 rpm.

B.P = $\left(\frac{2\pi N}{60}\right)$ x T

Torque (T) : = $\left(\frac{60}{2\pi N}\right)$ x BP

= $\left(\frac{60\times26.967}{2\pi\times1060}\right)$

T = 242.93 NM

4. Brake Pad Area and Pressure:

Pad Area = (108.6 x 38.2)

= 4148.52 mm^2

Disc Dimensions: D = 230 mm d = 142.6 mm

Uniform Pressure Theory

T = $\frac{2}{3}$ x Fa x $\frac{\mu(D^3-d^3)}{(D^2\times d^2)}$

Fa = $\frac{3}{2}$ x T $\frac{(D^2\times d^2)}{\mu(D^3\times d^3)}$

Fa = $\frac{3}{2}$ x 242.9 x 10^3 x $\frac{(230^2-142.6^2)}{0.41\,(230^3-142.6^3)}$

Fa = 3122.75N

Pressure = $\frac{Fa}{Area\ Of\ Brake\ Pad}$

= $\frac{3122.75}{4148.52}$ = 0.75 N / mm^2

Uniform Wave Theory,

T = Fa x μ x $\left(\frac{D+d}{4}\right)$

Fa =$\frac{\text{T x 4}}{\mu(\text{ D+ d})}$ = $\frac{4\times242.9\times10^3}{0.41\times(230+142.6)}$ == 6360 N

Pressure = $\frac{Fa}{Area\ Of\ BreakPad}$

=$\left(\frac{6360}{4148.52}\right)$

Pressure = 1.53 N/mm^2

= 1.53 Mpa

5. Temperature Rise in Disc:

Case 1: Single Stop Braking

Mass of Vehicle = 1340 Kg

V = 120 Kmph = 33.33 m/s

Braking Percentage Front Rear = 65.35

Static Weight Distribution = 60:40

Disc of Rotor Mass = 3 kg

Cv = 0.475 KJ/KgK

K = Correction Factor

Energy Absorbed by Brakes:

Eb = k/2 mv^2

= $\frac{1.15}{2}$ x 1340 x 33.33^2

= 855.9 KJ

Energy on Front Brakes:

$E_{f\,r\,b}$ = $\left(\frac{x}{x+y}\right)$ x $\frac{Eb}{2}$

= $\frac{65}{100}$ x $\frac{855.9}{2}$

=278.16

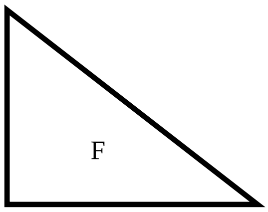
$E_{f\,r\,b}$ = MCv $\Delta\,Tf$

Temperature Rise: Δ Tf = 195.2 k

Final Temperature:
Ti = 30℃ = 303 k
Δ Tf = Tf – Ti
Tf = ΔTf + Ti = (165.2 + 303) = 498.2 k
= 225.2℃ @120 kmph
= 165^0c @ 100 kmph.

Case 2: Car going down a hill with continuous braking

Δh = 1000m



Energy Absorbed:
Eb = mgΔh
= 1340 x9.81 x1000
Eb = 13.14 x 10^6 J

Energy on Front Brakes:
$E_{f\,r\,b} = \frac{A}{A+B} X \frac{\text{Eb}}{2}$
= 0.6 x $\frac{13.14\ x\ 10^3}{2}$
=3.943MJ
$E_{f\,r\,b}$ = MCvΔT

Temperature Rise:
$\Delta T = \left(\frac{E_{f\,r\,b}}{MCv}\right)$
$= \frac{3.943\ X\ 10^3}{3\ X\ 0.475}$
= 2767K
Ti=303k

Final Temperature:
$T_f = \Delta T$ + Ti

T_f =3070k -303k

$T_f = 2797°C$

In conclusion, the numerical analysis of the ventilated disc rotor highlights critical parameters essential for ensuring effective braking performance and safety. The calculated kinetic energy, stopping distance, braking force, and power distribution between the front wheels reveal that the braking system efficiently manages the vehicle's deceleration under various conditions.

Modelling of the Disc Rotor

The rotor is modeled using the standard dimensions, which are measured using vernier calipers. These measurements aid in determining the amount of heat produced by the rotor. SOLIDWORKS (2022) software is used to model the disc rotor. With conventional dimensions, we can create a 3D representation of the disc rotor.

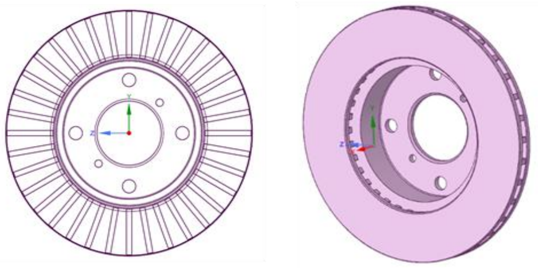


Figure 1: Ventilated Disk Rotor

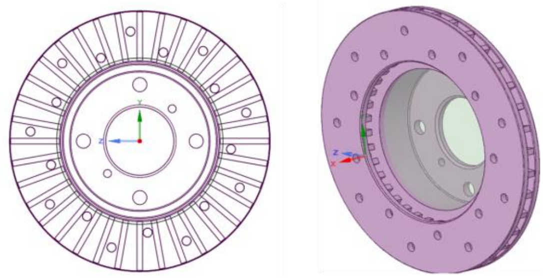


Figure2: Ventilated Disk Rotor with 7 mm cross Drill

In summary, the 7 mm hole size was selected to optimize cooling efficiency, structural strength, weight reduction, ease of manufacturing, and adherence to proven engineering standards for reliable and efficient disk rotor performance.

Thermal Analysis of Disk Rotor

The comparison highlights the thermal performance differences between a Ventilated Disk and a Ventilated Disk with Cross Drill. The Ventilated disc, being a fully dense structure, demonstrates uniform temperature distribution with a maximum temperature of 165°C. However, due to the absence of ventilation holes, it relies primarily on conduction and surface convection for heat dissipation, which limits its cooling efficiency. This design is prone to thermal stress and slower cooling, making it less ideal for applications involving high or repeated thermal loads. In contrast, the Ventilated Disk with Cross Drill. The Ventilated disc incorporates perforations and ventilation channels that enhance airflow and promote more effective heat dissipation through convection. While the maximum temperature on its surface also reaches 165°C, the overall cooling performance is significantly improved, reducing thermal stress and the likelihood of warping or fatigue. The hollow design is better suited for high-performance or heavy-duty applications where rapid cooling and thermal resilience are critical.

Overall, the ventilated design offers superior thermal management compared to the Ventilated Disk.

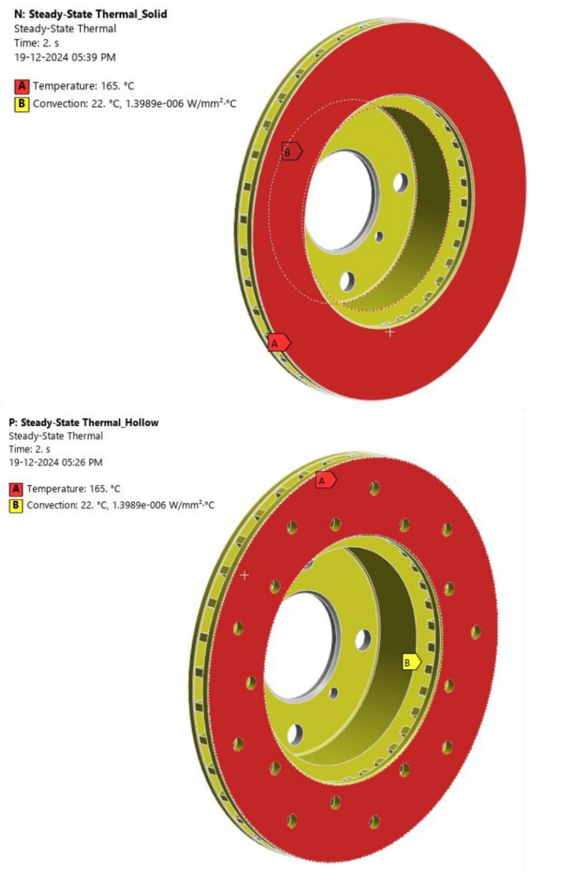


Figure 3: Steady – state Thermal solid Analysis ventilated disk

The Figure 4 shows thermal analysis comparison of a Ventilated Disk and a Ventilated Disk with Cross Drill to evaluate their heat dissipation performance. Both disks reach the same maximum temperature of 165°C, but the Cross Drill has a slightly lower minimum temperature of 150.8°C compared to 150.91°C for the Ventilated Disk. This slight difference suggests that the hollow disk has a broader temperature range, indicating better heat dissipation. The Ventilated Disk shows a uniform temperature gradient from the outer edge to the center, but it retains heat more effectively, leading to higher localized temperatures. In contrast, the Cross Drill disk exhibits improved cooling due to its vented design, which facilitates air circulation and reduces heat buildup. This makes the hollow disk more efficient at managing thermal loads, especially in high-performance or prolonged braking conditions. Overall, while the Ventilated Disk is simpler, the Cross Drill disk is better suited for applications requiring enhanced thermal performance and durability.

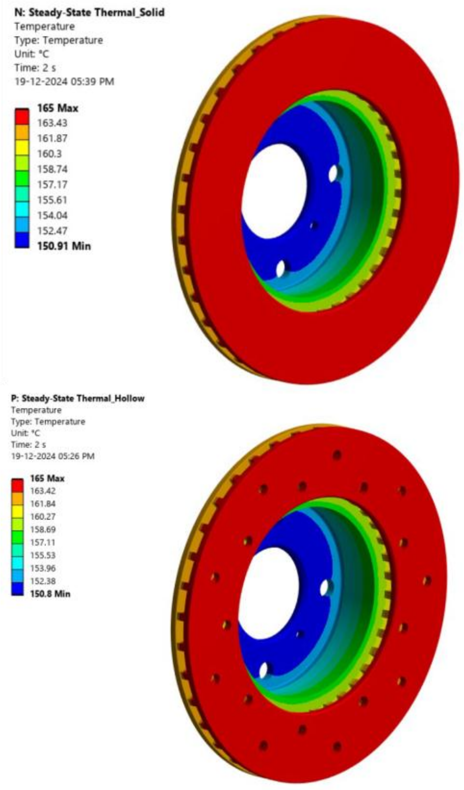


Figure 4: Different Temperatures for disk

The thermal analysis shown in figure 5 of ventilated and cross drill disks focuses on their heat flux distribution and efficiency. The ventilated disk exhibits a significantly higher maximum heat flux of 0.028322 W/mm² compared to the cross drill disk's 0.0030548 W/mm². This indicates that the ventilated disk experiences a higher rate of heat transfer in localized areas, leading to concentrated thermal gradients. The heat distribution in the ventilated disk is more uniform toward the center but lacks the cooling advantages provided by vents, resulting in inefficient dissipation and a greater risk of thermal fatigue. On the other hand, the cross drill disk, with its vented design, shows a less intense but more distributed heat flux pattern. The airflow facilitated by the vents effectively reduces thermal hotspots and promotes improved heat dissipation across the disk. While the solid disk may handle moderate braking demands, the cross drill disk is better suited for high-performance or prolonged braking scenarios due to its superior thermal management and reduced susceptibility to localized overheating.

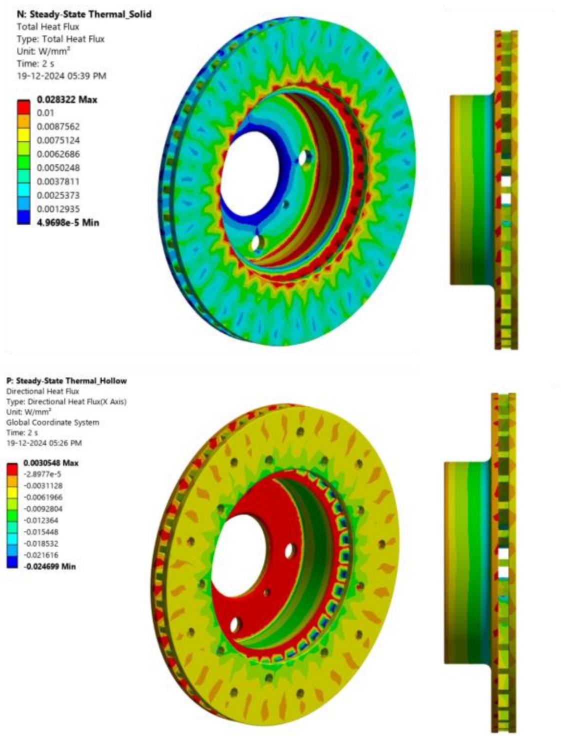


Figure 5: Directional Heat Flux for Disk

The analysis of total heat flux at the vanes emphasizes the critical role of design in thermal performance for brake disks. In the case of the ventilated disk, the maximum heat flux is measured at 0.023612 W/mm², with a minimum of 0.0044501 W/mm². The heat is concentrated along specific regions near the edges of the vanes, revealing a lack of uniform heat dissipation. This limited distribution suggests that the ventilated disk relies heavily on conduction through its material, as it lacks any structural features, such as vents, to promote active cooling. As a result, the heat buildup in these localized areas can lead to higher thermal gradients and potential thermal fatigue under prolonged braking conditions. On the other hand, the cross drill disk exhibits a slightly higher maximum heat flux of 0.024135 W/mm² and a minimum of 0.0044901 W/mm². The design of the vented vanes and cross drill allows for significantly improved airflow through the disk, enabling convective cooling alongside heat conduction. This results in a more evenly distributed heat flux across the vanes, reducing the risk of localized overheating. The airflow facilitated by the vented design continuously carries heat away from critical areas, enhancing the disk's overall thermal efficiency and performance. This improved distribution also means that the cross drill disk can maintain a lower average temperature during repeated or sustained braking events.

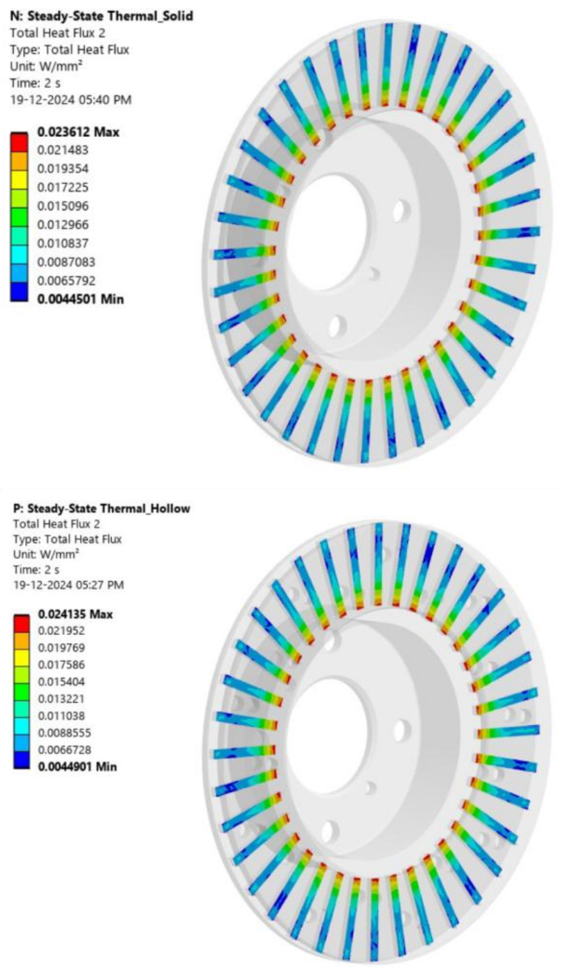


Figure 6: Total Heat Flux for Disk at Vans

Structural Analysis of Disk Rotor

Fixed support (a): this is applied to the inner hub of the rotor (yellow region). It represents a physical constraint that prevents any translational or rotational movement of the hub. This is a common boundary condition used to mimic how the rotor would be fixed to a shaft or other mounting structure in real-world applications. It ensures the hub remains stationary while the rest of the rotor is subjected to loads.

Pressure (b and d): a uniform pressure of 1.53 mpa is applied to the surfaces of the rotor (red areas). This pressure could represent aerodynamic or fluid forces acting on the rotor during operation, such as in a turbine, compressor, or braking system. The two labels, b and d, indicate that this pressure is applied on different surfaces, ensuring a realistic simulation of loading conditions on both sides of the rotor.

Rotational velocity (c): the rotor is set to rotate at 111 radians per second. This boundary condition simulates the operational spinning of the rotor, generating centrifugal forces that influence the stress distribution. The rotational speed creates tension in the material, especially near the outer edges, which must withstand the combined effects of pressure and rotational forces.

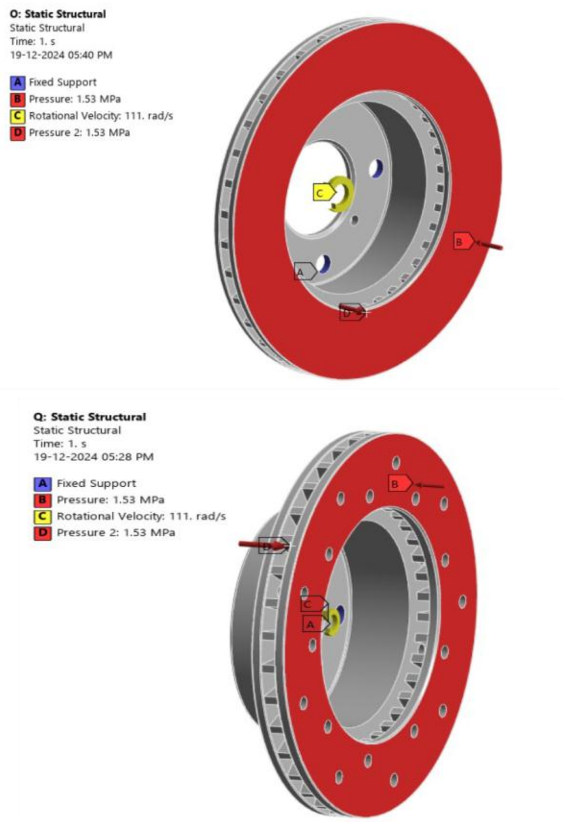


Figure 7: Boundary condition for structural analysis

The von-Mises stress analysis of a Cross drill disk rotor, illustrating how stress is distributed across its structure under loading conditions. In both views, the high-stress regions (red zones) are prominently concentrated around the bolt holes and the inner mounting area, where the disk is subjected to significant loads and force transfer. These stress concentrations arise due to geometric discontinuities and the sharp transitions around the mounting holes.

Red Zones (High Stress, ~491–499 MPa): These are located around the bolt holes and the inner mounting surface, indicating stress concentrations caused by load transfer and geometric discontinuities.

Green and Yellow Zones (Moderate Stress, ~100–200 MPa): These areas are adjacent to the high-stress zones, showing intermediate stress levels radiating outward.

Blue Zones (Low Stress, ~0.44–50 MPa): Found primarily on the outer rim and flat surfaces, these regions experience minimal stress.

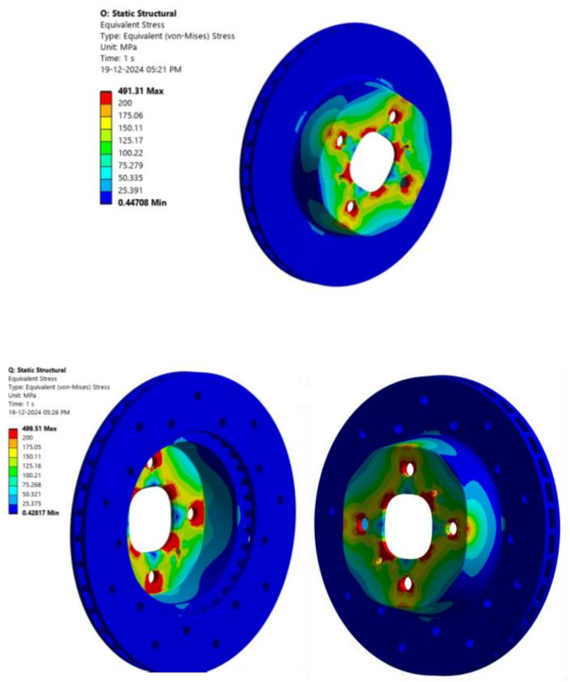


Figure 8: Equivalent (Von-Mises) stress analysis of Disk rotor

The Total Deformation Analysis of the disk rotor, as shown in the Figure 5.10, provides a clear representation of how the rotor responds to structural loads. The maximum deformation values are recorded as 0.18725 mm in the Ventilated and 0.18742 mm in the cross drilled disk, both occurring at the outer rim of the disk, represented by the red zones. This pattern is expected because the outer edges are farthest from the central hub, making them more susceptible to bending and displacement due to external loads and rotational forces. Moving inward, the deformation decreases progressively through yellow, green, and blue zones, with the inner hub and bolt-hole regions showing minimal deformation, close to 0 mm. These central zones, highlighted in dark blue, are fixed or heavily reinforced, offering structural stability and resistance to movement.

When comparing ventilated disk rotors and cross drilled disk rotor, the differences in deformation behavior become evident. Ventilated disk rotors display a smoother and more evenly distributed deformation pattern, with lower maximum deformation values across the structure. This is because the continuous material distribution offers better rigidity and structural stiffness, allowing loads to disperse more uniformly throughout the disk. In contrast, cross drilled disk rotors, while significantly lighter and more efficient in reducing rotational inertia, show higher localized deformation, particularly around the cutout regions near the central hub and along the edges of the drilled sections. These geometric discontinuities act as weak points, amplifying deformation and causing stress to concentrate in those areas.

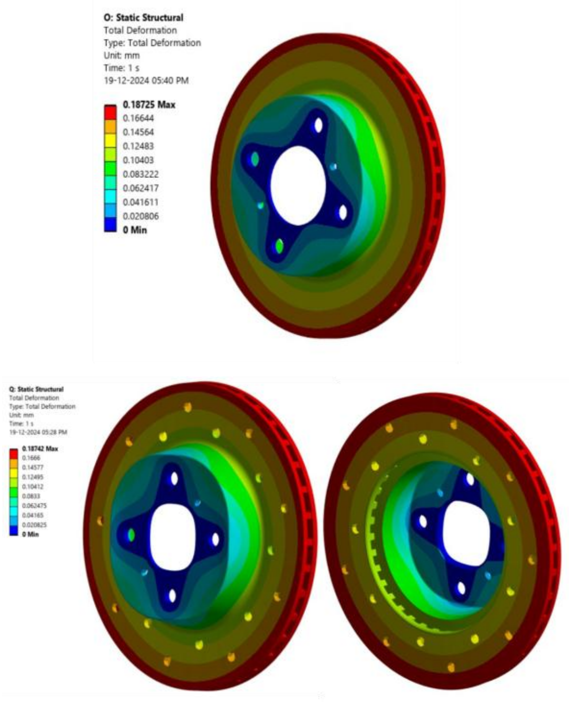


Figure 9: Total deformation analysis of Disk rotor

Safety Factor Distribution across the Disk

High Safety Factor Regions (Purple and Blue Zones, Max = 15): These regions cover the majority of the disk's surface**, particularly the outer rim and areas far from the bolt holes and mounting points. The high safety factor indicates that these zones are operating well within the material's strength limits and have a low risk of failure.

Moderate Safety Factor Regions (Green Zones, Safety Factor ~10): These areas are concentrated **around the inner mounting surface and cutout regions, indicating moderate stress levels. The structure here is more vulnerable than the outer regions but still maintains acceptable safety margins.

Low Safety Factor Regions (Red Zones, Min ~0.37): These critical zones are located around the bolt holes and sharp edges near the inner hub. The low safety factor suggests high stress concentration in these regions, making them susceptible to cracks, deformation, or fatigue failure under sustained loads.

Ventilated vs. Cross Drilled Disk Rotor Comparison

In the Ventilated disk rotor (purple zones dominate): The safety factor is generally higher and more uniformly distributed across the surface. There are fewer red zones, indicating better structural integrity and higher resistance to failure.

In the Cross Drilled disk rotor (blue dominates with visible red zones): The low safety factor regions are more pronounced, especially around the bolt holes and the edges of hollow cutouts. The hollow design reduces material stiffness, causing localized stress concentrations and lower safety margins in those areas.

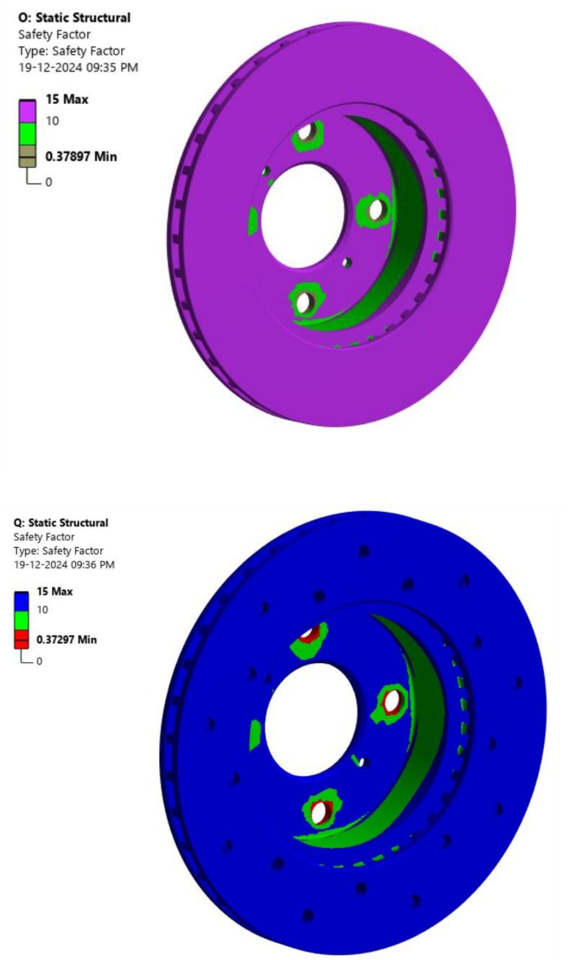


Figure 10: Safety Factor for Disk rotor

Machining of Disc Rotor

The Maruti Suzuki Wagon R car disc brake rotor is taken for machining process to ensure high performance and reliability. The process starts with turning, where the raw material is machined on a lathe to achieve the required outer and inner diameters, as well as a uniform thickness. This step ensures the rotor's surfaces are smooth and precise for further operations.

Next, CNC drilling is used to create evenly spaced holes on the rotor of 7 mm. These holes are designed to reduce weight, improve cooling efficiency, and dissipate heat generated during braking, preventing warping or overheating. Accurate positioning of these holes is crucial to maintain the rotor's rotational balance.

The rotor is then subjected to facing to ensure flat and smooth surfaces, which are essential for proper brake pad contact and uniform braking force. This step minimizes vibrations and ensures the braking system performs efficiently.

Finally, the rotor undergoes deburring to remove any sharp edges or burrs left from drilling or turning. This improves safety during handling and prevents cracks or imperfections. Throughout the process, precision measuring tools are used for quality control, ensuring that the rotor meets tight tolerances and is ready for safe and reliable operation in a braking system

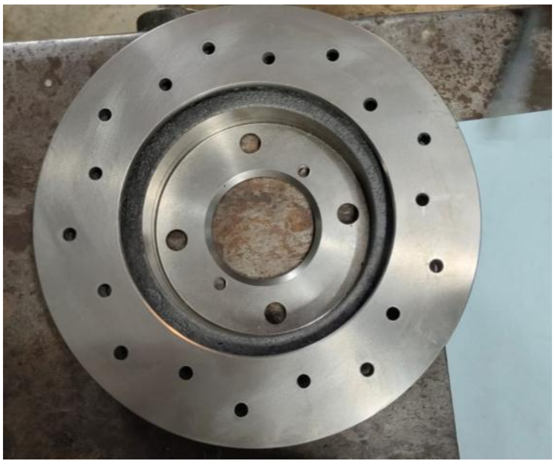


Figure 11: Ventilated Disk Rotor with 7 mm cross Drill

Testing Disc Rotor

The image 12 shows a cross-drilled brake rotor mounted on a Wagon R as part of a testing setup. The rotor, designed with drilled holes to improve heat dissipation and reduce weight, is securely attached to the vehicle's wheel hub using bolts. The brake calipers is positioned over the rotor, allowing the brake pads to make contact during operation. This test aims to evaluate the rotor's performance in terms of braking efficiency, heat management, and durability under real-world driving conditions.

Figure 12: Ventilated Disk Rotor with 7 mm cross Drill mounted on Wagon R

RESULTS AND DISCUSSION

Heat Dissipation:

Ventilated Gray Cast Iron Rotor:
The ventilated design improves airflow between the rotor's internal channels, allowing moderate heat dissipation during braking. However, prolonged or heavy braking can still lead to heat buildup due to limited cooling capacity. The following image shows the thermal results of each disk rotor for driving 80 km/h and sudden breaking

Figure 13: Ventilated Disk Rotor mounted on Wagon R

Ventilated Cross-Drilled Rotor:

The cross-drilled design significantly enhances heat dissipation by allowing additional airflow through the drilled holes. This reduces thermal stress and brake fade during high-speed or extended braking. In testing, the rotor exhibited up to 20–30% faster cooling rates compared to the standard ventilated rotor. The following image shows the thermal results of each disk rotor for driving 80 km/h and sudden breaking.

Figure 14: Ventilated Disk Rotor with 7 mm cross Drill mounted on Wagon R

Ventilated gray cast iron rotors are reliable and cost-effective, making them suitable for mass-market vehicles. They offer consistent braking in normal conditions but are prone to brake fading during high-stress scenarios like prolonged downhill braking. They are durable with a lower risk of cracking, though brake pads wear out faster due to less efficient cooling. Their heavier weight slightly impacts fuel efficiency and handling. On the other hand, ventilated cross-drilled rotors excel in heat dissipation, providing better braking performance and shorter stopping distances, even under stress. They are lighter by 5–10%, improving handling and marginally boosting fuel efficiency. However, they are more prone to cracking at drilled points under extreme stress and are more expensive due to complex manufacturing and quality control. The choice between the two depends on whether priority is given to cost-effectiveness and durability (gray cast iron) or enhanced performance and weight savings (cross-drilled).

CONCLUSION

The cross-drilled ventilated rotor demonstrates superior performance in terms of heat dissipation, braking consistency, and reduced brake fade, making it ideal for high-performance or hilly terrain applications. However, these advantages come with increased manufacturing costs, a slight risk of cracking under extreme conditions, and slightly higher noise levels. For everyday use in urban and highway conditions, the ventilated gray cast iron rotor is a reliable and cost-effective choice. On the other hand, the ventilated cross-drilled rotor is better suited for drivers who frequently face demanding braking scenarios or require enhanced braking performance. For the Maruti Suzuki Wagon R, adopting cross-drilled rotors may enhance safety and braking efficiency, especially in demanding conditions, but regular monitoring for wear and tear is recommended.

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