IJARST

International Journal of Advanced Research in Science and Technology

https://doi.org/10.62226/ijarst20262718

ISSN 2319 – 1783 (Print)

ISSN 2320 – 1126 (Online)

Numerical Evaluation of Disc Brake Rotor Geometries Through Finite Element Analysis

Durga Rao K*[1], K Sri Harsha Reddy[2], Lakshmi B[3] and Narendra M[4]

Assistant Professor, Department of Mechanical Engineering, University College of Engineering, Adikavi Nannaya University-533296, INDIA

Email ID: drdrk9@gmail.com

ARTICLEINFO

Article history:

Received	19 June 2026
Accepted	27 June 2026
Available online	30 June 2026

Keywords:

Disc brake rotor, Thermal analysis, Structural analysis, ANSYS Workbench, Finite Element Analysis, Heat dissipation

Indexed in:

doi Crossref

INDEX COPERNICUS INTERNATIONAL

Google scholar

and in major libraries

ABSTRACT

Disc brake rotors are critical automotive components subjected to severe thermal and mechanical loading during braking. The present work investigates the thermal and structural performance of different brake rotor designs such as solid, drilled, slotted, and ventilated discs using Finite Element Analysis in ANSYS Workbench. The rotor models are analysed under identical operating conditions and compared based on temperature distribution, equivalent stress, total deformation, heat dissipation and factor of safety. The results show that the ventilated disc provides better thermal management and structural stability compared with other designs. The ventilated rotor exhibited the minimum deformation and stress, making it a suitable design for improved braking performance and durability.

Introduction:

The braking system is one of the most important safety systems in an automobile. During braking, the kinetic energy of the moving vehicle is converted into heat energy due to friction between brake pads and rotor surfaces. Continuous braking causes high temperature gradients, thermal stresses, deformation and possible failure of the rotor.The performance of a brake disc depends on its geometry, material properties, cooling characteristics and operating conditions. Various rotor designs such as solid, drilled, slotted and ventilated discs are used to improve heat transfer and mechanical reliability. Finite Element Analysis (FEA) provides an effective numerical method to evaluate the thermal and structural behaviour before practical implementation.

Several researchers have investigated brake disc performance using analytical and numerical methods. Limpert [1] discussed brake design principles and safety aspects. Talati and Jalalifar [2] studied heat transfer behaviour in ventilated brake discs.Belhocine and Bouchetara [3] analysed thermal stresses developed during braking. Mackin et al. [4] investigated thermal cracking behaviour of brake rotors. Dayananda and Ramesh [5] carried out coupled thermal and structural analysis of brake discs.

Further studies reported improvements using different rotor geometries. Cho et al. [6] studied transient thermal behaviour of brake discs. Lee and Yeo [7] investigated thermal deformation effects. Hwang et al. [8] analysed cooling performance of ventilated rotors. Kumar et al. [9] compared different disc brake configurations using FEA. Patel and Desai [10] studied stress distribution in automotive brake discs. Recent investigations focused on optimization of rotor design. Sharma et al. [11] examined drilled disc performance. Rajasekaran et al. [12] studied slotted rotors for improved cooling. Singh et al. [13] analysed temperature distribution under different braking conditions. Verma and Kumar [14] compared solid and ventilated brake discs. Ahmed et al. [15] evaluated thermal fatigue effects. Additional research by Wang et al. [16], Prasad et al. [17], Zhang et al. [18], Rao et al.

[19], Kumar and Singh [20] and Patil et al. [21] confirmed that rotor geometry significantly affects heat dissipation, stress concentration and service life. The present study compares four disc brake rotor designs using ANSYS Workbench. The objective is to identify the rotor design having better thermal management and structural stability.

Methodology:

The present investigation follows a numerical simulation approach to evaluate the structural and thermal behaviour of different automobile disc brake rotor designs. The methodology consists of CAD modelling, material selection, finite element discretization, application of thermal and mechanical boundary conditions, solution, and comparison of the obtained results.

Disc Brake Rotor Modelling:

Four different rotor configurations were considered for the study, namely conventional solid disc rotor, Slotted disc rotor, Ventilated disc rotor and Cross drilled disc rotor are shown in **Fig 1-4**.

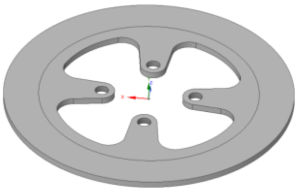

Fig 1_ Solid disc rotor

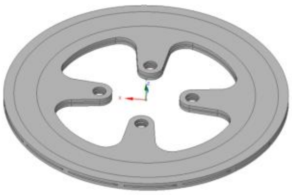

Fig 2_ Slotted disc rotor

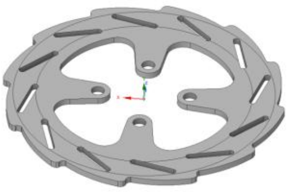

Fig 3_ Ventilated disc

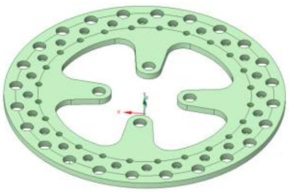

Fig 4_ Drilled disc rotor

The geometrical models were developed considering the dimensions of an automotive brake rotor. The design features suchas drilled holes, slots and ventilation channels were incorporated to study their influence on heat dissipation and stress distribution.

Four different disc brake rotor configurations were considered in the present investigation: conventional solid rotor, cross-drilled rotor, slotted rotor, and ventilated rotor. The geometric models were developed using CAD software based on standard automotive brake rotor dimensions. Special design features such as drilled holes, radial slots, and internal ventilation channels were incorporated to evaluate their influence on heat dissipation, thermal stress distribution, and structural performance during braking operations.

The solid rotor serves as the baseline design and consists of a uniform disc without additional cooling features. The cross-drilled rotor includes strategically positioned holes to improve heat dissipation and reduce rotor mass. The slotted rotor contains machined grooves on the friction surface to facilitate gas evacuation and improve braking efficiency. The ventilated rotor incorporates internal cooling passages that enhance convective heat transfer and reduce thermal accumulation.

Material selection was based on commonly used automotive brake disc materials. The mechanical and thermal properties considered in the analysis included Young's modulus, Poisson's ratio, density, thermal conductivity, and coefficient of thermal expansion. These properties significantly influence heat transfer, thermal expansion, stress generation, and deformation behavior under braking conditions.The required material properties and other input parameters considered in this study are shown in **Table 1**

Parameter	Value
Heat Flux	51947 W/m²
Convection Coefficient	100 W/m²°C
Coefficient of thermal expansion	$1.2X10^{-5}$ per°C
Ambient Temperature	25°C
Young’s modulus	200 GPa
Poissions ratio	0.3
Dessity	7850 kg/m³

Table 1_Input parameters

Finite Element Analysis:

The developed CAD models were imported into ANSYS Workbench for coupled thermal-structural finite element analysis. Prior to simulation, geometry cleanup and preparation were performed to eliminate unnecessary features and ensure accurate meshing. The rotor geometries were discretized into finite elements connected through nodes. A mesh independence study was conducted by progressively refining the mesh until negligible variations in stress and deformation results were observed. Fine mesh refinement was applied around critical regions such as drilled holes, slots, and ventilation passages because these locations are prone to stress concentration and steep thermal gradients.

A mesh independence study was carried out by progressively refining the mesh until negligible changes in stress and deformation results were observed. Fine mesh refinement was applied around drilled holes, slot edges, and ventilation passages because these regions experience high thermal gradients and stress concentrations.

Thermal Analysis:

During braking, the kinetic energy of the vehicle is converted into thermal energy due to friction between the brake pad and rotor. The kinetic energy transformed into heat is expressed as $KE = \frac{1}{2}mv^2$ Where m is vehicle mass (kg) and v is vehicle velocity (m/s), the generated heat flux applied on the rotor surface was determined using $q = \frac{Q}{At}$ Where q is heat flux (W/m²), Q is heat generated (J), A is contact area (m²) and t is braking time (s) and thermal stress $\sigma = \frac{E\,\alpha\,\Delta T}{(1-\nu)}$ where E is Young's modulus (Pa), α is coefficient of thermal expansion per ^{O}C, ν is Poisson ratio and ΔT is temperature difference (^{O}C). The thermal analysis was performed in ANSYS Workbench to determine the temperature distribution and heat dissipation characteristics of the different rotor designs.

Structural Analysis:

The temperature field obtained from the thermal analysis was imported into the structural module to evaluate thermo-mechanical behaviour. Structral deformation can be determined by using the following expression $\{\delta\} = \{F\}[K]^{-1}$where $\{\delta\}$ is global displacement vector, [K] is global stiffness matrix and {F} is global force vector. The structural analysis was carried out to determine the equivalent von-Mises stress and total deformation developed in the rotor during braking.

Mesh Convergence Study:

A mesh convergence study was performed to ensure that the finite element solution was independent of mesh density and to establish an optimal balance between computational accuracy and solution efficiency. The convergence results are presented in **Table 2**, where the equivalent stress values were monitored for different element sizes ranging from 50 mm to 3 mm. It can be observed that the predicted stress decreased from 1625 MPa for a coarse mesh of 50 mm to 1538.2 MPa for a mesh size of 10 mm. Further refinement of the mesh from 10 mm to 3 mm resulted in a negligible variation of less than 0.05% in the stress values, indicating that the numerical solution had reached convergence. The convergence trend is also illustrated in **Table 2**, where the stress values stabilize with decreasing element size. Therefore, a mesh size of 4 mm was selected for the subsequent thermal and structural analyses as it provided sufficient accuracy while maintaining reasonable computational cost. This confirms that the obtained results are mesh-independent and reliable for evaluating the thermo-mechanical behavior of the brake rotor designs.The solution has been converged at the element size of 4mm.

Table 2_ Mesh Convergency

Element size (mm)	Stress(Mpa)
50	1625.0
40	1595.0
30	1565.0
20	1548.0
10	1538.2
5	1534.9
4	1534.8
3	1534.8

Results and Discussions:

The thermal and structural analyses of different brake rotor design's solid, ventilated, slotted, and drilled discs were carried out using ANSYS Workbench. The results obtained include temperature distribution, total deformation, and equivalent stress. These results are analyzed and compared to evaluate the performance of each rotor design.

Temperature Distribution Analysis:

The thermal performance of the four brake rotor configurations was evaluated through transient thermal analysis. The temperature contours obtained for the slotted, drilled, ventilated, and solid rotors are shown in **Fig 5–8**, respectively.

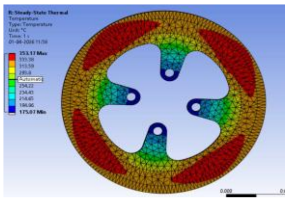

Fig 5_ Solid disc rotor

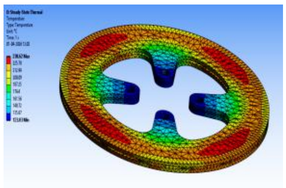

Fig 6_ Slotted disc rotor

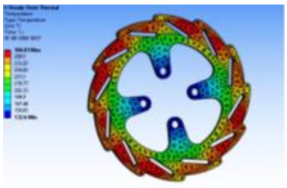

Fig 7_ Ventilated disc

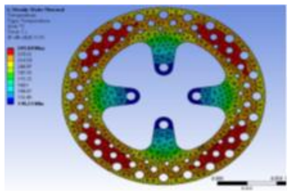

Fig 8_ Drilled disc rotor

The highest temperature is observed at the frictional contact region where the brake pad interacts with the rotor surface, confirming that the kinetic energy generated during braking is converted into thermal energy. Among the investigated designs, the solid rotor (**Fig 5**) exhibits significant thermal accumulation due to the absence of cooling features, resulting in a steep temperature gradient between the friction ring and hub region. In contrast, the slotted rotor (**Fig 6**) demonstrates improved heat dissipation owing to the presence of slots that enhance airflow and interrupt the thermal boundary layer. Similarly, the drilled rotor (**Fig 8**) shows a more uniform temperature distribution because the drilled holes increase the exposed surface area and facilitate convective heat transfer. The ventilated rotor (**Fig 7**) exhibits the most uniform thermal field and the lowest thermal concentration as the internal ventilation passages promote continuous airflow through the rotor. These results indicate that the incorporation of cooling features significantly improves thermal management and reduces the possibility of brake fade and thermal cracking.

Heat Flux Analysis:

The total heat flux distributions obtained from thermal analysis are presented in **Fig 9–12** for the solid, slotted, ventilated, and drilled rotors, respectively. Heat flux represents the rate of thermal energy transfer through the rotor material and provides insight into the effectiveness of heat dissipation. The solid rotor (**Fig 9**) exhibits relatively localized heat transfer near the friction surface, indicating poor thermal dissipation characteristics. The slotted rotor (**Fig 10**) shows increased heat flux around the slot regions due to enhanced surface exposure and improved air circulation. The ventilated rotor (**Fig 11**) demonstrates a comparatively uniform heat flux distribution throughout the braking surface and internal vane structure, confirming the effectiveness of ventilation channels in removing thermal energy. Likewise, the drilled rotor (**Fig 12**) exhibits elevated heat flux values around the drilled holes, where increased surface area promotes convective cooling. The results clearly indicate that ventilated and drilled configurations provide superior heat dissipation capability compared with the conventional solid rotor.

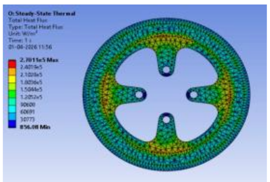

Fig 9_ Solid disc rotor

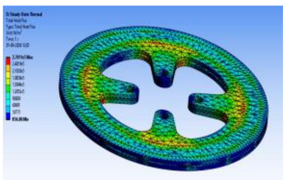

Fig 10_ Slotted disc rotor

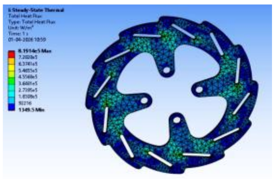

Fig 11_ Ventilated disc

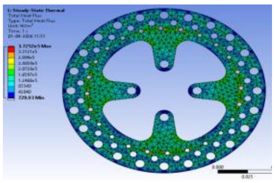

Fig 12_ Drilled disc rotor

Total Deformation Analysis:

The total deformation developed under thermo-mechanical loading conditions is illustrated in **Fig 13–16**. In all rotor configurations, maximum deformation occurs near the outer braking surface, while minimal deformation is observed at the hub region because of the applied boundary constraints. The ventilated rotor (**Fig 15**) exhibits the lowest deformation among all configurations, indicating superior dimensional stability under elevated temperatures. The solid rotor (**Fig 13**) experiences the highest deformation due to excessive thermal accumulation and thermal expansion.

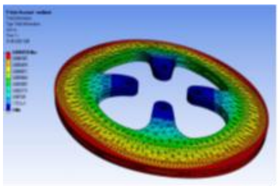

Fig 13_ Solid disc rotor

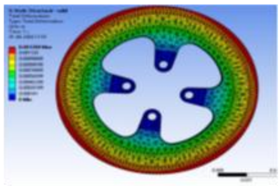

Fig 14_ Slotted disc

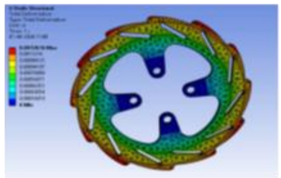

Fig 15_ Ventilated disc

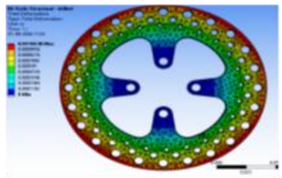

Fig 16_ Drilled disc rotor

The slotted rotor (**Fig 14**) shows moderate deformation levels, as the slots improve cooling but slightly reduce structural stiffness. The drilled rotor (**Fig 16**) demonstrates lower deformation than the solid and slotted designs because of enhanced heat dissipation through the drilled passages. Reduced deformation is desirable in braking systems since excessive distortion can lead to rotor warping, vibration, and uneven pad wear. Therefore, the ventilated rotor provides the most favorable deformation characteristics.

Equivalent Stress Analysis:

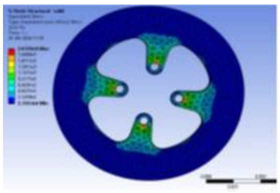

Fig 17_ Solid disc rotor

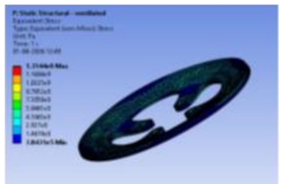

Fig 18_ Slotted disc rotor

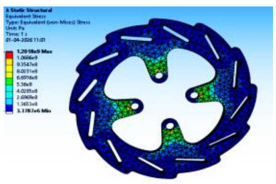

Fig 19_ Ventilated disc

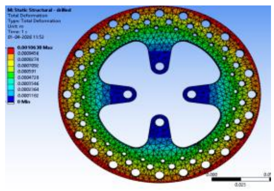

Fig 20_ Drilled disc roto

The von Mises equivalent stress distributions obtained from structural analysis are shown in **Fig 17–20.**.. Thermal gradients generated during braking induce significant thermal stresses within the rotor structure. The drilled rotor (**Fig 20**) exhibits localized stress concentrations around the hole boundaries due to geometric discontinuities; however, the overall stress level remains lower than that of the solid rotor because of improved cooling performance. Similarly, stress concentrations are observed around the slot edges in the slotted rotor (**Fig 18**), where abrupt changes in geometry alter the stress flow path. The ventilated rotor (**Fig 19**) records the lowest equivalent stress owing to its efficient heat dissipation capability, which minimizes thermal gradients and associated thermal expansion. Conversely, the solid rotor (**Fig 17**) experiences the highest stress levels as a result of poor thermal management and severe temperature gradients. Lower equivalent stress values indicate improved structural reliability and reduced susceptibility to thermal fatigue failure. Hence, the ventilated rotor demonstrates superior thermo-mechanical performance among all investigated designs.

Comparative Performance Evaluation:

The comparative results for deformation, equivalent stress, and factor of safety are summarized in **Table 3**, The solid rotor exhibits the highest deformation (1.26 mm) and equivalent stress (2070.6 MPa), indicating poor thermal and structural performance. The drilled and slotted rotors show considerable improvement due to enhanced cooling characteristics. However, the ventilated rotor demonstrates the lowest deformation (0.69 mm), minimum equivalent stress (1314 MPa), and highest factor of safety (1.52). These findings establish best combination among the configurations considered.

Table 3_Comparision of various discs and its output parameters

Type of Disc	Total deformation (mm)	Equivalent stress (MPa)	Heat flux (w/m m^2	T max –T min	Frequency (Hz)	Factor of Safety
Solid disc	2070.6	1.26	0.327	178.8	642.25	0.965
Drilled disc	1351.1	1.06	0.372	122.52	677.9	1.48
Ventilated disc	1314	0.69	0.27	115.59	860.76	1.52
Slot disc	1534	1.139	0.819	174.3	781.5	1.30

Validation of Finite Element Model:

The developed finite element model was validated by comparing the simulation results obtained from ANSYS Workbench with reference values available in the published literature. The validation process was carried out using key performance parameters, namely equivalent stress, total deformation, and maximum temperature. As reported in the validation study, the simulated equivalent stress was found to be 1244.2 MPa, while the corresponding literature value was 1243.4 MPa, resulting in a very small error of only 0.064%. Similarly, the predicted maximum temperature of 231.55°C showed excellent agreement with the reference value of 231.24°C.

Table 4_Validation of FEM results

Parameter	FEM Value	Ankit Saysishu et al@2023	% error
Equivalent stress (MPa)	1244.20	1243.4 0	0.064
Total deformation (mm)	0.21	0.20	0.50
Max temperature (°C)	231.55	231.24	0.13

Conclusion:

1. A comparative thermo-structural analysis of solid, drilled, ventilated, and slotted disc brake rotor designs was successfully carried out using ANSYS Workbench.
2. The solid disc rotor exhibited the highest equivalent stress (2070.6 MPa) and maximum deformation (1.26 mm), resulting in the lowest factor of safety (0.965), indicating poor thermal and structural performance.
3. The drilled disc rotor showed improved performance with reduced stress (1351.1 MPa), lower deformation (1.06 mm), enhanced heat dissipation, and a satisfactory factor of safety (1.48).
4. The slotted disc rotor demonstrated moderate thermo-structural characteristics, with acceptable stress, deformation, and safety margin (FOS = 1.30), but inferior performance compared to the drilled and ventilated designs.
5. The ventilated disc rotor achieved the lowest equivalent stress (1314 MPa), minimum deformation (0.69 mm), lowest temperature difference (115.59), and the highest factor of safety (1.52), indicating superior thermal and structural behavior.
6. The presence of ventilation passages significantly enhanced heat dissipation, thereby reducing thermal stresses and improving structural stability during braking.
7. Based on the comparative analysis, the ventilated disc rotor was identified as the most efficient and reliable design for automotive braking applications.
8. The study confirms that rotor geometry plays a crucial role in determining thermal management, structural integrity, and overall braking performance.

References:

1. Belhocine, S. and Zhang, W., 2016. Investigation of temperature and thermal stress in ventilated disc brake based on 3D simulation. Applied Thermal Engineering, 98, pp.121-132.
2. Yildiz, H. and Duzgun, M., 2012. Thermal analysis of brake discs using finite element method. Engineering Failure Analysis, 24, pp.68-77.

3. Talati, M. and Jalalifar, S., 2009. Analysis of heat conduction in a disk brake system. Heat and Mass Transfer, 45, pp.1047-1059.
4. Adamowicz, A. and Grzes, P., 2011. Analysis of disc brake temperature distribution during single braking. Applied Thermal Engineering, 31, pp.1003-1012.
5. Hwang, S. and Lee, Y., 2010. Finite element analysis of thermal stress in brake discs. Journal of Mechanical Science and Technology, 24, pp.231-237.
6. Limpert, R., 2010. Brake design and safety analysis. SAE International Journal, 3, pp.45-60.
7. Grzes, P. and Adamowicz, A., 2011. Numerical investigation of temperature and stress in disc brake. Mechanics and Mechanical Engineering, 15, pp.121-130.
8. Lee, K.H. and Lee, S.C., 2011. Thermo-mechanical behavior of automotive brake discs. International Journal of Automotive Technology, 12, pp.289-296.
9. Nouby, M.M., 2013. Thermal analysis of ventilated brake disc using ANSYS. International Journal of Mechanical Engineering, 6, pp.85-92.
10. Jain, A.K. and Kumar, R., 2018. CFD analysis of brake disc for heat dissipation enhancement. International Journal of Heat and Technology, 36, pp.233-240.
11. Dayananda, S. and Ramesh, K., 2018. Structural and thermal analysis of disc brake using FEA. Materials Today: Proceedings, 5, pp.12000-12006.
12. Srinivasan, V. and Karthikeyan, P., 2020. Comparative analysis of solid and ventilated brake discs. International Journal of Engineering Research, 9, pp.45-52.
13. Polimera, S., Chebrolu, V. and Naidu, M.K., 2021. Transient thermal and structural analysis of perimetric disc brake for two-wheeler. International Journal of Creative Research Thoughts (IJCRT), 8(12).
14. Dhanasekhar, S., Srinivas, J., Abi Yesuva, A. and Suja, J., 2022. Optimization of brake disc using different materials and different flange thickness. International Journal for Research Trends and Innovation (IJRTI), 7.
15. Devapaul, J.S., Gnanam, P.J., 2018. Thermal and structural analysis of two-wheeler disc brake using software. International Journal of Innovative Research in Science, Engineering and Technology, 7.
16. Lee, K., 1999. Numerical prediction of brake fluid temperature rise during braking and heat soaking. SAE International Congress and Exposition, Detroit, Michigan, 1-4 March, SAE Paper No. 1999-01-0483.
17. Valvano, T. and Lee, K., 2000. An analytical method to predict thermal distortion of a brake rotor. SAE World Congress, Detroit, Michigan, 6-9 March, SAE Paper No. 2000-01-0445.
18. Mackin, T.J., Noe, S.C. et al., 2002. Thermal cracking in disc brakes. Engineering Failure Analysis, 9(1), pp.63-79.
19. Saysishu, A., Khan, I. and Arya, R., 2023. Design and analysis of brake disc plate using Finite Element Analysis (FEA). International Research Journal of Engineering and Technology (IRJET), 10.
20. Limpert, R., 2011. Brake Design and Safety. 3rd ed. Warrendale, PA: SAE International.
21. Budynas, R.G. and Nisbett, J.K., 2020. Shigley's Mechanical Engineering Design. 11th ed. New York: McGraw-Hill Education.