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Structural And Thermal Analysis of Disc Brake Using Solid Work

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ABSTRACT

The braking system is the most crucial safety component in an automobile, primarily responsible for decelerating the vehicle by converting kinetic energy into thermal energy through friction. This research presents a comprehensive Structural and Thermal Analysis of a disc brake rotor to evaluate its performance under varying operational conditions. The primary objective is to investigate the effects of material substitution and geometric thickness variation on the rotor's durability and heat dissipation capabilities. In this study, the disc brake rotor is meticulously designed using SolidWorks CAD software, ensuring accurate geometric parameters and specialized features like ventilation holes. The model is then subjected to Finite Element Analysis (FEA) using SolidWorks Simulation tools. The analysis is bifurcated into two domains: Steady-State Thermal Analysis to determine temperature distribution and heat flux, and Static Structural Analysis to calculate Von-Mises stresses and total deformation.

The performance of the standard Grey Cast Iron rotor is compared against alternative materials such as Stainless Steel and Titanium. Simultaneously, the rotor thickness is varied (22 mm, 24 mm, and 26 mm) to analyze the trade-off between mass reduction and structural stability. The simulation results provide critical insights into identifying the optimal material-thickness configuration that minimizes thermal fatigue and "brake fade" while maintaining structural integrity. This study serves as a predictive tool for enhancing the safety and efficiency of automotive braking systems

Key words: Disc Brake Rotor, SolidWorks, FEA, Thermal Analysis, Structural Integrity, Grey Cast Iron, Titanium, Stainless Steel, Brake Fade

1. INTRODUCTION

The automotive braking system is the most critical safety feature of any vehicle, designed to decelerate or stop a moving vehicle by converting kinetic energy into thermal energy through friction. Among various types, the disc brake is widely preferred in modern automobiles due to its superior heat dissipation and stable performance under high-speed conditions. A typical disc brake system consists of a rotor (disc) that rotates with the wheel and a stationary caliper containing brake pads. When the brake pedal is pressed, hydraulic pressure forces the pads against the rotor, generating immense friction. This process results in a rapid rise in temperature, which can reach several hundred degrees Celsius within seconds.

However, repeated or prolonged braking leads to a phenomenon known as "Brake Fade," where the friction coefficient drops significantly due to overheating, potentially leading to brake failure. Furthermore, the combination of high mechanical pressure and extreme thermal gradients induces significant structural stresses, which may cause warping, surface cracking, or permanent deformation of the rotor. Traditional materials like Grey Cast Iron are reliable but heavy, prompting researchers to explore alternatives like Stainless Steel and Titanium to improve fuel efficiency and performance while maintaining structural integrity.

To address these challenges, modern engineering relies on Computer-Aided Design (CAD) and Finite Element Analysis (FEA) to predict rotor behavior before physical manufacturing. This research utilizes SolidWorks for high-fidelity 3D geometric modeling, allowing for precise adjustments in rotor thickness. Subsequently, SolidWorks Simulation is employed to perform a coupled structural and thermal analysis. By simulating various material properties and thickness configurations (22 mm, 24 mm, and 26 mm), this study aims to optimize the disc brake design for maximum thermal stability and structural integrity, ensuring a safer and more efficient braking performance in contemporary vehicles

2. OBJECTIVE

The primary objective of this research is to conduct a comprehensive structural and thermal evaluation of an automotive disc brake rotor to enhance its performance and safety. The study aims to utilize SolidWorks CAD software for the precise 3D geometric modeling of ventilated disc rotors, followed by detailed Finite Element Analysis (FEA) using SolidWorks Simulation tools. A core focus of the investigation is to analyze the heat dissipation characteristics through steady-state thermal analysis and to determine the resulting Von-Mises stresses and total deformation under peak braking loads via static structural analysis. Further more, the research seeks to perform a comparative study between conventional materials, such as Grey Cast Iron, and advanced alternatives, including Stainless Steel and Titanium. By systematically varying the rotor thickness (22 mm, 24 mm, and 26 mm), the study intends to identify the optimal balance between structural integrity and thermal resistance, ultimately providing a data-driven recommendation for a lightweight, high-performance brake rotor configuration that minimizes the risk of brake fade and mechanical failure.

3. DESIGN AND CALCULATION

3.1. Geometric Design Parameters

The ventilated disc brake rotor was designed based on standard automotive specifications. The modeling was performed in SolidWorks with a focus on three thickness variations (22mm, 24mm, 26mm). The fixed design parameters used for all iterations are summarized in Table 1

Table 1: Geometric Dimensions of the Rotor

Parameter	Value	Unit
Outer Diameter	240 - 280	mm
Inner Diameter	50 - 100	mm
Effective Radius	100 - 120	mm
Number of Ventilation Vanes	30 - 36	Nos.
Thickness Variations	18 - 24	mm

3.2 Braking Force Calculation

The braking force acting on the disc brake is determined based on the coefficient of friction between the brake pad and the disc surface. The frictional force is responsible for slowing down or stopping the rotating wheel.
The braking force can be calculated using the following formula:
F=μ×NF = \mu \times NF=μ×N
Where:
F=Frictional force (N)
μ = Coefficient of friction between brake pad and disc
N = Normal force applied on the disc (N)
Assuming:
Coefficient of friction (μ) = 0.35
Normal force (N) = 1000 N
Therefore, F=0.35×1000F = 0.35 \times 1000F=0.35×1000 F=350NF = 350 NF=350N Thus, the braking friction force acting on the disc brake is 350 N.

3.3 Braking Torque Calculation

The braking torque produced by the disc brake helps in reducing the rotational speed of the wheel.
The braking torque is calculated using the following formula:
T=F×rT = F \times rT=F×r
Where:
T = Braking torque (Nm)
F = Friction force (N)
r = Radius of brake disc (m)
Assuming the radius of the brake disc:
r = 120 mm = 0.12 m
Therefore,
T=350×0.12T = 350 \times 0.12T=350×0.12 T=42NmT = 42 NmT=42Nm
Hence, the braking torque generated by the disc brake is 42Nm

3.4 Material Selection

In this project, three different materials are selected for the disc brake in order to evaluate their structural and thermal performance. The materials considered are:

- Stainless Steel
- Gray Cast Iron
- Titanium

These materials are selected due to their good mechanical strength, thermal conductivity, and resistance to wear and corrosion. The comparison of these materials helps in determining the most suitable material for brake disc applications.

3.5 Disc Thickness Consideration

In order to study the effect of thickness on the structural and thermal performance of the brake disc, three different thickness values are considered in this project.

The thickness values used are:

- 26 mm
- 24 mm
- 22 mm

Structural and thermal analysis are performed for each thickness using SolidWorks Simulation. The results are compared in terms of stress distribution, deformation, and temperature variation.

Table 2: Material Properties of Stainless Steel,Titanium ,Gray cast iron

Property	Unit	Stainless Steel	Titanium	Gray cast iron
Density	Kg/m^3	8000	4430	7100
Young's Modulus	GPa	193	114	110
Poisson's Ratio	-	0.29	0.33	0.28
Thermal Conductivity	W/m.K	16.2	6.7	52
Specific Heat °C	J/Kg.K	500	526	447
Coeff. of Thermal Expansion	10^{-6}/°C	17.2	8.6	11

4.METHODOLOGY

4.1 Modelling in SolidWorks

This chapter describes the methodology followed for the structural and thermal analysis of the disc brake rotor. The study involves designing the disc brake rotor using SolidWorks software and performing simulation using SolidWorks Simulation tools.

Different rotor thicknesses and materials are considered to study their effect on stress, deformation, and temperature distribution. The overall objective is to evaluate the mechanical and thermal performance of the disc brake rotor under braking conditions.

4.2 CAD Modeling of Disc Brake Rotor

The disc brake rotor model is created using SolidWorks CAD software. The modeling process begins with creating a circular sketch representing the outer profile of the disc brake rotor. The sketch is then extruded using the Extrude Boss/Base feature to obtain the required rotor thickness.

The design includes several important features such as the outer braking surface, inner hub region, central hole, and mounting holes. Ventilation holes are also included in the rotor design to improve heat dissipation during braking.The ventilation holes are created using the Cut-Extrude feature and arranged around the rotor using the Circular Pattern tool. Fillet operations are applied to the edges of the rotor to remove sharp edges and improve the design quality. The completed CAD model is then prepared for simulation and analysis.

4.3 Thickness Variation of Disc Brake Rotor

Rotor thickness plays an important role in determining the structural strength and thermal performance of a disc brake. In this study, three different rotor thicknesses are considered to evaluate their effect on stress and deformation.

The selected rotor thickness values are: **26 mm**, **24 mm**, **22 mm**

Separate CAD models are created for each thickness in SolidWorks. These models are later used for structural and thermal analysis. The comparison of these models helps identify the most suitable thickness for the disc brake rotor.

Figure.1 Shows CFD Model of Disc Brake

5. MESHING OF THE DISC BRAKE

The reliability of the thermo-mechanical simulation is highly dependent on the discretization of the rotor geometry. In this study, the ventilated disc was modeled using three-dimensional isoparametric tetrahedral elements. These elements are ideal for conforming to the complex curvatures of the ventilation vanes and mounting holes.

To ensure high-precision results, a local mesh refinement strategy was applied specifically to the disc-pad contact zone. This is critical because the contact interface experiences the highest thermal and mechanical gradients during braking. the mesh was refined in these strongly deformed zones to accurately capture the rapid temperature variations and localized stress concentrations.

To validate the mesh quality, a convergence study was performed. This process ensures that the simulation results (Maximum Temperature and Von-Mises Stress) are independent of the mesh density. Based on the convergence criteria, the final optimized models were established:

- Thermal Analysis Mesh: 95,189 nodes and 65,016 elements (High-density for thermal gradients).
- Static Structural Mesh: 43,161 nodes and 28,042 elements (Optimized for stress distribution

6. RESULTS AND ANALYSIS

6.1 (a) Gray Cast Iron

Following fig. shows results of total deformation, equivalent stress and temperature distribution of cast iron after analysis

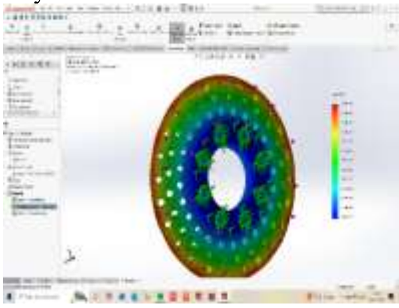
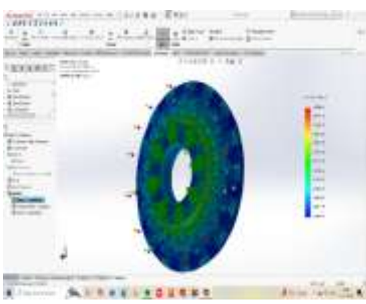
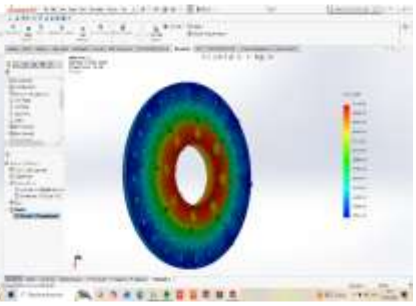

Figure. 2 Total deformation **Figure. 3** Equivalent Stress **Figure.4** Temperature Distribution

6.2 (b) Stainless Steel

Following fig. shows results of total deformation, equivalent stress and temperature distribution of stainless steel after analysis.

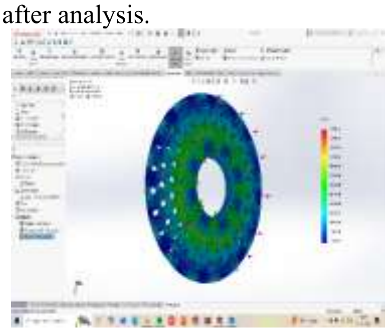
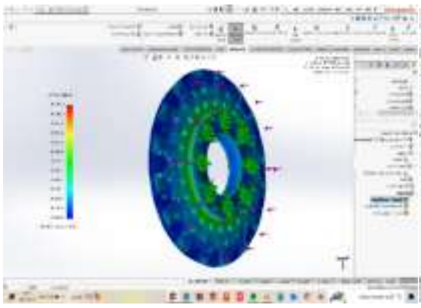
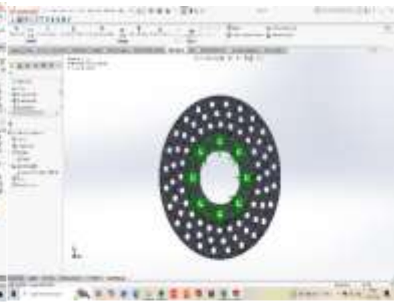

Figure.5 Total deformation **Figure.6** Equivalent Stress **Figure.7** Temperature Distribution

6.3 (c) Titanium

Following fig. shows results of total deformation, equivalent stress and temperature distribution of Titanium after analysis

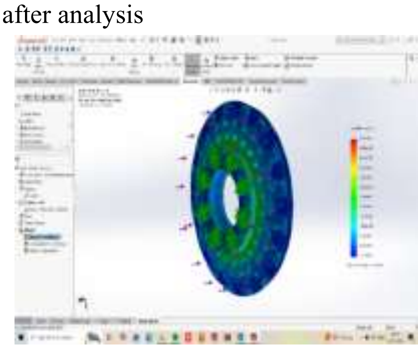
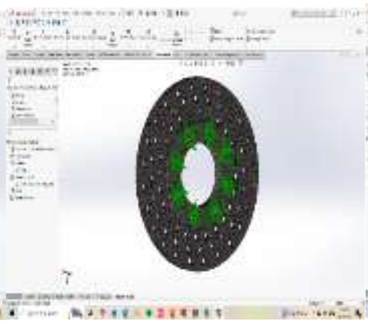
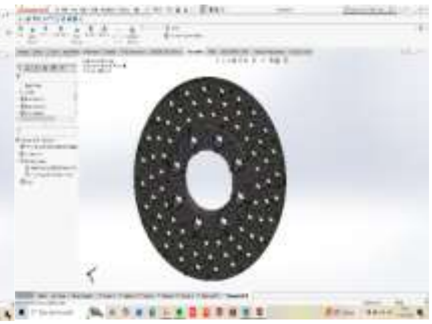

Figure. 8 Total deformation **Figure.9** Equivalent Stress **Figure.10** Temperature Distribution

Table no. 3 Results of Different Materials

Result	Gray Cast iron		Stainless Steel		Titanium	
	Max	Min	max	min	max	min
Total deformation (M)	1.8974	0	1.0738	0	2.1513	0
Equivalant Stress(Pa)	109.48	1.0818	115.86	1.068	114.93	1.769
Temperature distribuation (c)	473.23	280	469.54	272.92	470.12	280

7. CONCLUSION

The structural and thermal analysis of the disc brake rotor was successfully performed for Gray Cast Iron, Stainless Steel, and Titanium. From the comparative study, the following conclusions are reached:

- **Overall Best Material:** Gray Cast Iron is the most suitable material for standard automotive applications. It showed the lowest maximum stress (109.48 Pa) and provided superior heat dissipation due to its high thermal conductivity (52 W/m.K)
- **Structural Stability:** Stainless Steel exhibited the lowest total deformation (1.0738) making it the most rigid material for high-pressure braking conditions.
- **Lightweight Performance:** Titanium is identified as the best choice for racing applications due to its high strength-to-weight ratio, despite having a higher deformation rate compared to steel.
- **Design Validation:** The equivalent stress for all three materials remained significantly below their Yield Strength, confirming that the rotor design is structurally safe under a 1,000 N braking load.
- **Thermal Efficiency:** The integration of ventilation vanes effectively managed the high heat flux (1,000,000 W/m), maintaining the rotor temperature within safe operational limits
- **Thermal Conductivity** is the most critical property for a brake rotor. Gray Cast Iron is superior because its high conductivity prevents overheating and ensures consistent braking performance.

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