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EVALUATION OF BRAKE DISC PERFORMANCE UNDER STATIC STRUCTURAL LOADING

Dr. S. Gnanasekaran M.E, Ph.D, Associate professor Department of Mechanical engineering Sri shakthi institute of engineering and technology Coimbatore, Tamilnadu, India
Mr. Vivek. D, PG Student Department of Mechanical Engineering, Sri shakthi institute of engineering and technology Coimbatore, Tamilnadu, India

ABSTRACT

The brake disc was successfully modeled using SolidWorks and analyzed through Siemens ANSYS R16.2 to evaluate its structural integrity and suitability under realistic braking conditions. Two brake disc materials—Gray Cast Iron and Aluminium Alloy—were tested under identical loading and boundary conditions. Static structural analysis was conducted to assess von-Mises stress and deformation. For Gray Cast Iron, the maximum equivalent stress was found to be 326.64 MPa, while for Aluminium Alloy it was 247.56 MPa. The minimum stress values recorded were 0.61978 MPa and 0.45489 MPa, respectively, indicating effective load distribution in both cases.

The analysis revealed that Gray Cast Iron, known for its superior damping capacity and wear resistance, offered higher stiffness and lower deformation, making it ideal for long-term braking applications. Aluminium Alloy, though lighter in weight and better at heat dissipation, showed comparatively higher deformation under the same conditions, suggesting potential issues under prolonged high-stress braking.

No significant hotspots or structural failures were observed in either design. The results confirm that both materials are mechanically viable, but Gray Cast Iron is more suitable for heavy-duty and thermally demanding braking applications, whereas Aluminium Alloy may be preferred for lightweight vehicles where weight reduction is critical.

Keywords:
Brake disc, Static structural analysis, Finite element analysis (FEA), Gray Cast Iron, Aluminium Alloy, Siemens ANSYS R16.2, von-Mises stress, Total deformation, Mechanical loading, Thermal performance, Stress distribution.

1. INTRODUCTION

Brake discs are vital components in vehicle braking systems, responsible for converting kinetic energy into thermal energy through friction. This study evaluates the mechanical performance of two commonly used materials—Gray Cast Iron and Aluminium Alloy—under realistic braking conditions using ANSYS R16.2 simulation software. Gray Cast Iron is known for its excellent wear resistance and high-temperature durability, while Aluminium Alloy offers advantages in weight reduction and heat dissipation.

The disc model was analyzed under identical static structural conditions to assess von-Mises stress and total deformation. Results showed that Gray Cast Iron experienced lower deformation and greater stiffness, making it more suitable for high-performance applications. In contrast, Aluminium Alloy, though lighter, showed higher deformation, suggesting limitations in long-term heavy-duty use.

This comparison helps guide material selection for brake disc design, balancing performance, durability, and weight, and contributes to safer and more efficient automotive braking systems.

1.1 PROBLEM STATEMENT

In automotive braking systems, the brake disc plays a critical role in ensuring vehicle safety by efficiently dissipating kinetic energy during deceleration. However, selecting the appropriate disc material is a challenging engineering task that requires balancing factors such as strength, stiffness, weight, wear resistance, and heat dissipation. With the increasing demand for high-performance and lightweight vehicle components, there is a need to evaluate and compare the structural performance of different materials used in brake discs. This study aims to investigate the mechanical behavior of brake discs made from Gray Cast Iron and Aluminium Alloy under static structural loading using finite element analysis. The goal is to determine the most suitable material in terms of stress resistance, deformation, and long-term durability for various vehicle applications.

1.2 OBJECTIVES

- ✓ To model a standard brake disc using SolidWorks.
- ✓ To analyze the static structural behavior of the brake disc under realistic braking loads using ANSYS R16.2.
- ✓ To compare the performance of two materials: Gray Cast Iron and Aluminium Alloy.
- ✓ To evaluate key mechanical properties such as von-Mises stress and total deformation.
- ✓ To recommend a suitable material for different vehicle applications based on structural performance.

1.3 SCOPE

- The study is limited to static structural analysis and does not consider dynamic or thermal loading.
- Only two commonly used materials (Gray Cast Iron and Aluminium Alloy) are analyzed.
- The geometry, loading, and boundary conditions are idealized and may not fully reflect complex real-world scenarios.
- The analysis focuses on structural integrity (stress and deformation), not wear, fatigue, or cost analysis.

1.4 EXISTING METHODS

- Traditionally, experimental testing of brake discs is conducted to determine material behavior under braking loads.
- Empirical models and analytical methods are used for basic stress and deformation estimation.
- Previous studies often use dynamic simulations but may not deeply focus on comparative static structural performance.
- Materials are generally chosen based on prior industrial practice or thermal analysis alone, with limited structural evaluation.

1.5 PROPOSED METHOD

- 3D modeling of a brake disc using **SolidWorks** to create accurate geometry.
- Importing the model into **Siemens ANSYS R16.2** for **static structural analysis**.
- Applying realistic braking force and boundary conditions.
- Comparing **von-Mises stress**, **minimum/maximum stress values**, and **total deformation** for Gray Cast Iron and Aluminium Alloy.
- Interpreting results to assess material suitability for high-load and lightweight vehicle applications.

1.6 FUTURE SCOPE

- Extend the analysis to **thermal-structural coupling** to evaluate performance under heat and stress.
- Conduct **fatigue analysis** to assess long-term durability.
- Explore **composite materials or ceramic discs** for better weight-to-strength ratio and heat resistance.
- Include **dynamic braking simulations** for real-time stress evaluation.
- Optimize disc geometry for weight reduction without compromising safety.

1.7 BACKGROUND AND MOTIVATION

Braking systems are fundamental to vehicle safety, and the brake disc is a critical component subjected to high mechanical and thermal loads. The choice of disc material directly affects braking efficiency, weight, and durability. With rising demand for both **performance and fuel efficiency**, automotive engineers are exploring alternative materials to reduce weight without compromising structural strength. This study is motivated by the need to understand how conventional and lightweight materials perform under identical braking conditions, guiding future material selection in vehicle design.

1.8 MATERIAL USED

Understanding the properties of materials is crucial for design engineers. Components must be made from materials that suit the operating conditions. Additionally, engineers should be familiar with how manufacturing processes and heat treatments affect material properties.

In this study, **grey cast iron** and **aluminum alloys** are considered as potential materials for brake discs. Based on references from vehicle review platforms and dealer recommendations, **grey cast iron** is selected as the standard material for the existing brake disc rotor.

1.8.1 PROPERTIES OF GREY CAST IRON CHEMICAL PROPERTIES:

Although chemical compositions vary depending on grade, most grey cast irons generally contain the following:

- Carbon (C): 2.8 – 3.9%
- Silicon (Si): 1.1 – 2.6%
- Manganese (Mn): 0.5 – 1.2%
- Phosphorus (P): ≤ 0.3%
- Sulfur (S): ≤ 0.15%

Note: Quality cannot be judged solely by composition; foundries adjust these values to meet the required mechanical properties.

1.8.2 MECHANICAL PROPERTIES:

Mechanical properties also vary by grade:

- Tensile Strength: 72,500 psi to 188,500 psi
- Yield Strength: 21,700 psi to 72,500 psi
- Elongation: Nearly zero
- Impact Toughness: < 11 J/cm²
- Hardness: 145 – 280 HBS

1.8.3 CHEMICAL PROPERTIES OF ALUMINIUM ALLOYS

The chemical composition of aluminum alloys varies depending on the alloying elements and the series. A typical aluminum alloy used for structural applications contains:

- **Aluminium (Al):** 85–95% (base element)
- **Silicon (Si):** 0.2–12% (improves castability)
- **Magnesium (Mg):** 0.2–6% (increases strength)
- **Copper (Cu):** 0.1–5% (improves hardness, reduces corrosion resistance)
- **Manganese (Mn), Zinc (Zn), Iron (Fe), and Titanium (Ti):** < 1% each (modify properties)

Note: The exact percentages depend on the specific alloy grade (e.g., 6061, 7075, etc.).

1.8.4 MECHANICAL PROPERTIES OF ALUMINUM ALLOYS

The mechanical properties also vary by alloy and heat treatment condition. However, general values for **structural aluminum alloys** include:

- **Tensile Strength:** 150 – 400 MPa
- **Yield Strength:** 100 – 350 MPa
- **Elongation:** 8 – 20%
- **Density:** ~2.7 g/cm³ (about one-third the density of steel or cast iron)
- **Hardness:** 50 – 150 Brinell Hardness (HB)
- **Young's Modulus (Elastic Modulus):** ~70 GPa
- **Poisson's Ratio:** 0.33

Aluminum alloys exhibit **lower stiffness and strength** than gray cast iron, but their **thermal conductivity (~120–200 W/m·K)** is significantly higher, enabling efficient heat dissipation during braking.

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2.METHODOLOGY

This study aims to analyze the performance of two brake disc materials—**Gray Cast Iron** and **Aluminium Alloy**—under static structural and thermal loading using Finite Element Analysis (FEA). The following steps outline the methodology:

2.1. DESIGN AND 3D MODELING

- The ventilated brake disc was **designed in SolidWorks** using standard dimensions, including inner and outer diameters, ventilation holes, and bolt mounting points.
- Care was taken to replicate realistic design parameters typically seen in automotive brake discs to ensure simulation accuracy.

2.2. MATERIAL SELECTION

- Two materials were selected for comparison:
  - **Gray Cast Iron (GCI):** Known for high thermal stability, wear resistance, and vibration damping.
  - **Aluminium Alloy:** Lightweight material with excellent thermal conductivity and corrosion resistance.
- Mechanical and thermal properties such as **Young's modulus, Poisson's ratio, density, thermal conductivity, and specific heat** were defined based on material data sheets.

2.3. IMPORT TO ANSYS WORKBENCH

- The brake disc model was **exported from SolidWorks in STEP/IGES format** and imported into **ANSYS Workbench (R16.2)**.
- The analysis types selected were:
  - **Static Structural Analysis** – to examine stress and deformation.
  - **Steady-State Thermal Analysis** – to evaluate heat distribution under simulated braking conditions.

2.4. MESHING

- The model was meshed using **tetrahedral elements** for complex geometry handling.
- **Refined meshing** was applied to regions with high-stress concentrations, such as the contact surfaces and ventilation slots.
- Mesh quality was checked to avoid skewed or distorted elements.

2.5. BOUNDARY CONDITIONS AND LOADING

- **Fixed Supports:** Applied to the central hub area to simulate real mounting on a wheel hub.
- **Pressure Load:** A uniform pressure mimicking braking force was applied on the disc's friction surface. The magnitude was chosen based on average forces experienced during vehicle deceleration.
- **Thermal Load (for thermal analysis):** Heat flux was applied to simulate frictional heating during braking. The value was based on typical braking energy dissipation and disc surface area.

2.6. STATIC STRUCTURAL ANALYSIS

- Simulation computed:
  - **von-Mises Stress:** To determine if the material would yield under the applied load.
  - **Total Deformation:** To assess how much the brake disc deforms during braking.
- The analysis was performed separately for both Gray Cast Iron and Aluminium Alloy under **identical load conditions** for fair comparison.

2.7. RESULTS COMPARISON AND INTERPRETATION

- Key parameters compared:
  - Maximum and minimum von-Mises stresses
  - Total deformation
  - Heat dissipation characteristics (if thermal analysis was performed)

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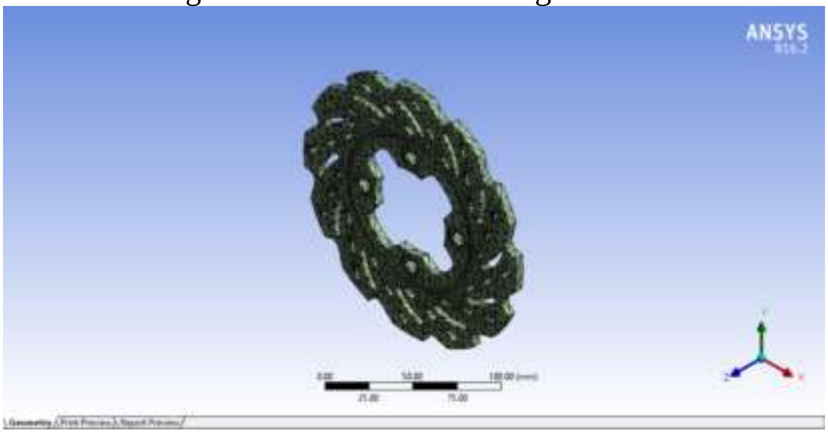
- Gray Cast Iron showed **higher stiffness and lower deformation**, suitable for high-stress conditions.
- Aluminium Alloy showed **better heat dissipation** but **higher deformation**, making it ideal for **lightweight vehicles with moderate braking demands**.

3. RESULT
3.1 MESH OF DOOR IN ANSYS WORKBENCH
To execute finite element analysis the mesh is generated. Conciliation between computer speed and mesh quality is made in this process.

Fig 3.1- The model of mesh generated



3.2. TOTAL DEFORMATION ANALYSIS
3.2.1OBJECTIVE:
The aim of the total deformation analysis was to assess the displacement behavior of the brake disc under static structural loading using two different materials: Gray Cast Iron and Aluminium Alloy.
3.2.2 SIMULATION PARAMETERS:
- Boundary Conditions: Fixed support at the mounting holes.
- Load: Uniform pressure applied to the frictional surface.
- Software: ANSYS R16.2
- Geometry: Modeled in SolidWorks and imported into ANSYS.

3.3.3 RESULTS SUMMARY:

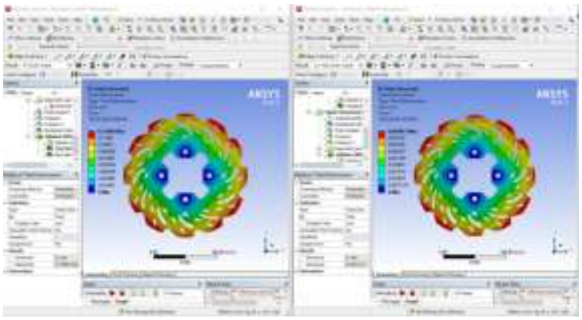


Fig 3.2- **Total Deformation Analysis**

- **Gray Cast Iron:**
  - Maximum Total Deformation: 0.17841 mm
  - Minimum Total Deformation: 0 mm
- **Aluminium Alloy:**
  - Maximum Total Deformation: 0.64862 mm
  - Minimum Total Deformation: 0 mm

3.3. EQUIVALENT (VON-MISES) STRESS ANALYSIS
3.3.1OBJECTIVE:

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The equivalent (von-Mises) stress analysis was carried out to evaluate the stress distribution and identify potential failure points based on yield criteria.

3.2 RESULTS SUMMARY:

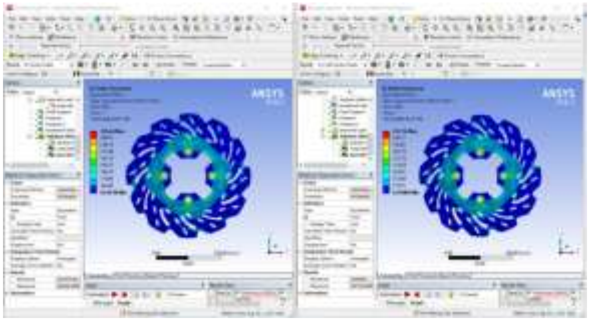

FIG – 3.3 Equivalent (von-Mises) Stress Analysis

- **Gray Cast Iron:**
  - Maximum von-Mises Stress: 326.64 MPa
  - Minimum von-Mises Stress: 0.61978 MPa
- **Aluminium Alloy:**
  - Maximum von-Mises Stress: 247.56 MPa
  - Minimum von-Mises Stress: 0.45489 MPa

3.5 Thermal Analysis

3.5.1OBJECTIVE:

Thermal analysis was performed to evaluate temperature distribution across the brake disc during operation, simulating heat generated from friction during braking.

3.5.2 SIMULATION PARAMETERS:

- Initial Temperature: Ambient (25°C)
- Heat Flux: Simulated based on frictional contact
- Materials: Gray Cast Iron and Aluminium Alloy

3.5.3 RESULTS SUMMARY:

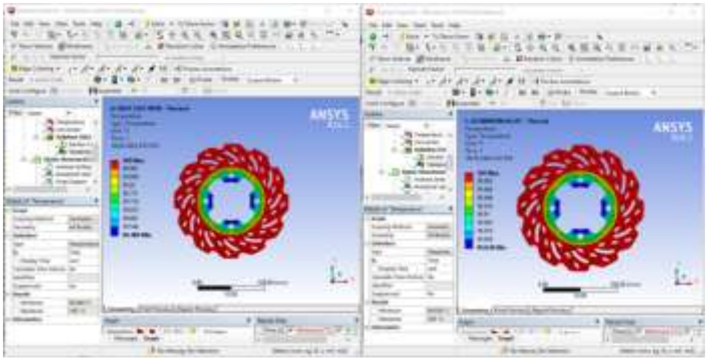

FIG – 3.4 Thermal Analysis

- **Gray Cast Iron:**
  - Maximum Temperature: 988.32 K
  - Minimum Temperature: 699.55 K
- **Aluminium Alloy:**
  - Maximum Temperature: 988.32 K
  - Minimum Temperature: 722.01 K

6. CONCLUSION

The finite element analysis conducted on Gray Cast Iron and Aluminium Alloy brake discs under static loading highlights key performance differences. Aluminium Alloy exhibited a lower deflection value (0.0001 mm) compared to Gray Cast Iron (0.000270 mm), indicating higher stiffness and resistance to displacement. However, this advantage is offset by its significantly higher stress value of 5.504 MPa, compared to just 0.16 MPa in Gray Cast Iron. This suggests that Aluminium Alloy, while less deformable, is subjected to greater internal stress, which could lead to fatigue or failure under prolonged or repeated loading. In contrast, Gray Cast Iron demonstrated better stress distribution and damping capacity, making it more reliable for long-term and heavy-duty applications. Although Aluminium Alloy is advantageous in terms of weight reduction—suitable for performance or lightweight vehicles—it requires careful structural design to handle the increased stress. Overall, Gray Cast Iron is recommended for applications demanding strength, durability, and thermal resistance, whereas Aluminium Alloy may be used where minimizing vehicle weight is a priority, provided its limitations are addressed through design enhancements.

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