

# COMPARATIVE THERMAL AND STRUCTURAL ANALYSIS OF AIRCRAFT BRAKE DISC MATERIALS

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## ABSTRACT

**This paper presents a comparative study of aircraft brake disc materials using thermal and structural analysis. The materials considered include Grey Cast Iron, Silicon Carbide (SiC) reinforced composite, and Titanium alloy. A three-dimensional model of the brake disc was developed and analyzed using ANSYS software by applying appropriate boundary conditions such as heat flux and convection. The performance of each material was evaluated based on temperature distribution, stress, and deformation characteristics. The results indicate that Silicon Carbide composite provides superior thermal resistance and uniform heat distribution, whereas Titanium alloy exhibits higher stress concentration due to lower thermal conductivity. Grey Cast Iron demonstrates balanced performance but is less efficient compared to advanced materials. The study highlights the importance of material selection in improving braking efficiency, safety, and durability in aircraft systems.**

**Keywords:** ANSYS, Brake Disc, Grey Cast Iron, Silicon Carbide, Structural Analysis, Thermal Analysis, Titanium Alloy

## I. INTRODUCTION

Aircraft braking systems are essential for safe landing and ground operations. During braking, a large amount of kinetic energy is converted into heat due to friction between the brake disc and pads. This results in high temperature generation, which significantly affects the performance and life of the braking system. Therefore, selecting suitable materials for brake discs is crucial. Conventional materials such as Grey Cast Iron are widely used due to their cost-effectiveness and acceptable performance. However, with increasing performance demands, advanced materials such as Silicon Carbide composites and Titanium alloys are being explored for improved thermal and structural properties. This study focuses on the comparative analysis of different brake disc materials using simulation techniques to evaluate their behavior under thermal and structural loads.

## II. PROBLEM DESCRIPTION

Aircraft braking systems are subjected to extreme thermal and mechanical loads during landing, where a large amount of kinetic energy is converted into heat due to friction. This results in high temperature generation, leading to thermal stresses, deformation, and potential material failure of the brake disc.

Traditional materials such as Grey Cast Iron, although widely used, have limitations in terms of weight, thermal resistance, and performance under high temperature conditions. With the advancement of aerospace technology, there is a need to identify alternative materials that can withstand high thermal loads while maintaining structural integrity and durability.

However, selecting the most suitable material requires a detailed analysis of thermal behavior, stress distribution, and deformation characteristics under realistic operating conditions. Therefore, this study focuses on evaluating and comparing different brake disc materials using simulation techniques to determine their effectiveness in improving braking performance, safety, and reliability in aircraft applications.

## III. LITERATURE REVIEW

Several studies have been conducted on the thermal and structural performance of brake disc materials under high-temperature operating conditions. Researchers have focused on improving heat dissipation, wear resistance, and structural integrity to enhance braking efficiency.

Grey Cast Iron has been widely used in conventional braking systems due to its good thermal conductivity and wear resistance. However, studies indicate that it has limitations in high-temperature applications due to increased weight and moderate thermal stability.

Recent research highlights the use of advanced materials such as Silicon Carbide (SiC) composites, which offer superior thermal

resistance, high strength, and improved wear characteristics. These materials are capable of withstanding extreme temperatures and provide better performance compared to traditional materials.

Titanium alloys have also been investigated due to their high strength-to-weight ratio and corrosion resistance. However, their relatively low thermal conductivity leads to heat accumulation, which can affect braking performance.

Based on previous studies, it is evident that advanced composite materials provide improved performance over conventional materials. This has led to the need for comparative analysis using simulation techniques, which forms the basis of the present study.

## IV. PROPOSED SYSTEM

The proposed system focuses on the comparative analysis of aircraft brake disc materials using simulation techniques. A three-dimensional model of the brake disc is developed and analyzed under thermal and structural loading conditions to evaluate material performance.

In this study, three different materials, namely Grey Cast Iron, Silicon Carbide (SiC) reinforced composite, and Titanium alloy, are selected for analysis. These materials are chosen based on their mechanical and thermal properties relevant to aircraft braking applications.

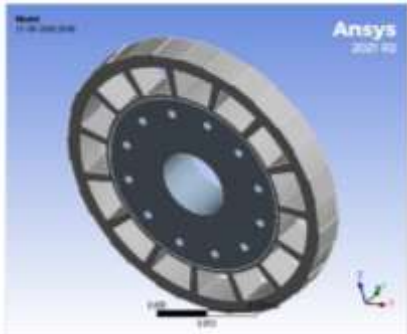
The brake disc model is subjected to realistic boundary conditions, including heat flux applied at the friction surface to simulate heat generation during braking, and convection to represent heat dissipation to the surrounding air. The analysis is carried out using ANSYS software.

Thermal analysis is performed to determine temperature distribution across the brake disc, while structural analysis is conducted to evaluate stress and deformation. The results obtained from each material are compared to identify the most

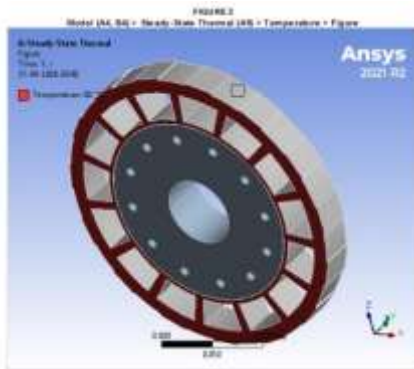
suitable material for improved braking efficiency, safety, and durability.

The proposed system provides a cost-effective and efficient method to evaluate material performance without the need for physical testing.

### **BRAKE DISC MODEL**



### **APPLIED TEMPERATURE BOUNDARY CONDITION**



### **V. WORKING PRINCIPLE**

The working principle of the aircraft brake disc is based on the conversion of kinetic energy into thermal energy through friction. During landing, the aircraft possesses high kinetic energy due to its velocity. When the braking system is applied, brake pads come into contact with the rotating brake disc, generating frictional force.

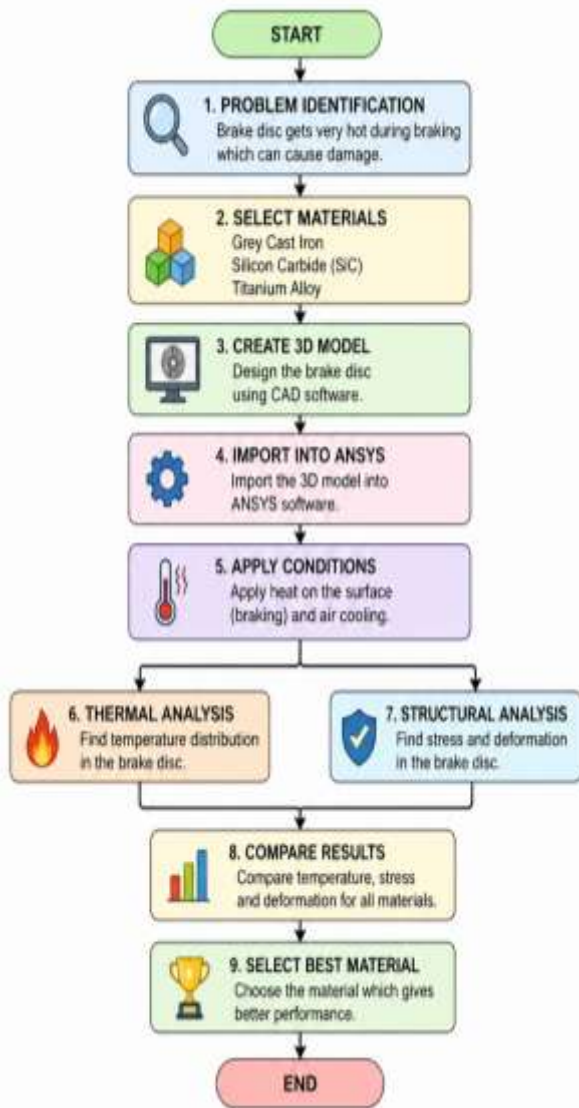
This frictional force opposes the motion of the wheel and gradually reduces its rotational speed,

thereby slowing down the aircraft. As a result of friction, a large amount of heat is generated at the contact surface between the brake pad and the disc. This heat is absorbed by the brake disc and then dissipated to the surrounding environment through conduction and convection.

In the proposed system, this process is simulated by applying heat flux on the friction surface to represent heat generation during braking. Convection boundary conditions are applied to simulate heat loss to the surrounding air. Thermal analysis is used to determine temperature distribution, while structural analysis evaluates stress and deformation caused by thermal and mechanical loads.

The efficiency of the braking system depends on the material properties of the brake disc, such as thermal conductivity, strength, and wear resistance. Therefore, different materials are analyzed to determine their suitability for aircraft braking applications.

## VI. FLOWCHART



## VII. RESULTS AND DISCUSSION

The present study investigates the thermal and structural behavior of a brake disc using finite element analysis under steady-state thermal and static structural conditions. The analysis was carried out by applying a temperature load of  $80^{\circ}\text{C}$  along with convective boundary conditions and structural pressure. The results obtained include temperature distribution, total heat flux, directional

heat flux, total deformation, equivalent elastic strain, and equivalent stress.

### A. Thermal Analysis

The steady-state thermal analysis provides insight into the temperature distribution across the brake disc. The results indicate that the temperature is relatively uniform, with a maximum value of approximately  $80^{\circ}\text{C}$  and a minimum value slightly lower, indicating minimal thermal gradients. This uniformity suggests that the applied thermal load is well distributed across the disc surface.

However, slight variations in temperature can be observed near the ventilation slots and inner regions of the disc. These variations are due to differences in geometry and heat dissipation through convection. The outer regions tend to retain slightly higher temperatures, while the inner regions experience marginal cooling.

The temperature distribution across the brake disc shows a maximum temperature of  $80^{\circ}\text{C}$  and a minimum of approximately  $79.7^{\circ}\text{C}$ , indicating a nearly uniform temperature field. The small temperature variation confirms that heat is evenly distributed across the disc. Slight cooling is observed near the inner regions and ventilation slots due to convective heat transfer.

### B. Heat Flux Analysis

The total heat flux results show how heat is transferred within the brake disc. The maximum heat flux is observed near the outer regions and edges of the disc, where heat dissipation is more active. The inner hub region exhibits significantly lower heat flux values, indicating limited heat transfer in that area.

The directional heat flux results further highlight the direction of heat flow. Positive and negative

values indicate the direction of heat transfer relative to the coordinate system. The results confirm that heat flows from regions of higher temperature to lower temperature, primarily from the outer surface towards the inner regions and surrounding environment.

These findings indicate that the brake disc effectively dissipates heat, which is critical for preventing thermal failure during braking operations.

The total heat flux results indicate a maximum value of approximately  $931 \text{ W/m}^2$  and a minimum close to  $0.008 \text{ W/m}^2$ , with an average around  $240 \text{ W/m}^2$ . Higher heat flux is observed near the outer surfaces, indicating effective heat dissipation. The inner hub region shows very low heat flux, confirming limited heat transfer in that area.

The directional heat flux varies between  $-789 \text{ W/m}^2$  to  $711 \text{ W/m}^2$ , indicating the direction of heat flow. Positive and negative values represent heat flowing in opposite directions along the defined axis

### C. Structural Analysis

The structural analysis was performed by applying pressure loads along with thermal effects to evaluate deformation and stress distribution.

#### 1) Total Deformation

The total deformation results show a maximum deformation of approximately  $8.53 \times 10^{-5} \text{ m}$ , while the minimum deformation is nearly zero at the fixed regions. The deformation is highest at the outer edge of the disc and lowest at the central hub. The low magnitude of deformation indicates good structural stiffness of the material.

#### 2) Equivalent Elastic Strain

The equivalent elastic strain ranges from approximately  $1.98 \times 10^{-8}$  to  $1.39 \times 10^{-3}$ , with an average value around  $8.15 \times 10^{-5}$ . Higher strain is observed near the inner hub region due to stress

concentration. However, the strain values remain within the elastic limit of the material.

#### 3) Equivalent (von-Mises) Stress

The equivalent stress varies from approximately  $4.25 \times 10^4 \text{ Pa}$  to  $4.86 \times 10^7 \text{ Pa}$ . Maximum stress is concentrated near the inner hub region, while the rest of the disc experiences lower stress levels. The stress values are within the allowable limits, indicating safe operation under the given loading conditions.

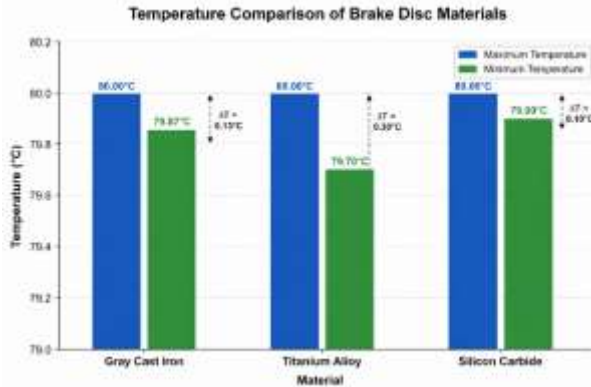
### D. Overall Discussion

The results demonstrate that the brake disc exhibits stable thermal behavior with minimal temperature variation. Heat dissipation is effective, particularly at the outer regions. Structurally, the disc shows very low deformation and controlled stress distribution. The combination of low deformation, acceptable stress levels, and uniform temperature distribution confirms that the brake disc performs efficiently under the applied thermo-mechanical conditions.

Based on the comparative results, the silicon material demonstrates superior thermal stability, while the titanium alloy provides an optimal balance between strength and deformation. Gray cast iron, although conventional, shows comparatively higher stress and deformation.

The present study is limited to steady-state thermal analysis with uniform temperature loading. Dynamic braking conditions, material wear, and transient thermal effects are not considered. Additionally, ideal boundary conditions are assumed, which may differ from real-time operating conditions.

## VIII. GRAPHS



### A. Temperature Comparison of Brake Disc Materials

The figure compares the maximum and minimum temperatures of Gray Cast Iron, Titanium Alloy, and Silicon Carbide brake disc materials. All materials reach a maximum temperature of 80°C, while the minimum temperatures are 79.87°C for Gray Cast Iron, 79.70°C for Titanium Alloy, and 79.90°C for Silicon Carbide. The small temperature differences indicate nearly uniform thermal distribution, with Silicon Carbide showing the least variation and Titanium Alloy showing slightly higher variation among the materials.

## VIII. CONCLUSION AND FUTURE SCOPE

### A. Conclusion

The present study evaluates the thermal and structural performance of aircraft brake disc materials, namely Gray Cast Iron, Titanium Alloy, and Silicon Carbide, using finite element analysis. The thermal analysis results indicate that all materials maintain a nearly uniform temperature distribution with a maximum temperature of 80°C. However, Silicon Carbide exhibits the least temperature variation, indicating superior heat dissipation characteristics.

The heat flux analysis shows that effective heat transfer occurs primarily at the outer regions of the disc, with Silicon Carbide demonstrating better

thermal conductivity compared to the other materials. Structural analysis results reveal that Gray Cast Iron exhibits the highest deformation ( $1.008 \times 10^{-4}$  m), while Titanium Alloy and Silicon Carbide show lower deformation values of  $8.53 \times 10^{-5}$  m and approximately  $7.80 \times 10^{-5}$  m, respectively.

The equivalent stress results confirm that all materials operate within safe limits; however, Titanium Alloy demonstrates superior strength due to its high load-bearing capacity. Overall, Silicon Carbide offers the best thermal performance and structural stability, making it the most suitable material among the three for high-performance braking applications.

### B. Future Scope

The present study is limited to steady-state thermal and static structural analysis under simplified boundary conditions. Future work can focus on transient thermal analysis to simulate real-time braking conditions and temperature fluctuations. Additionally, the effect of wear, frictional contact, and material degradation over repeated braking cycles can be investigated.

Further studies may also include experimental validation of simulation results and the use of advanced composite materials to enhance braking performance. Optimization techniques can be applied to improve disc geometry and cooling efficiency. The integration of coupled thermo-mechanical analysis and dynamic loading conditions would provide more realistic insights into brake disc performance in practical applications.

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