Thermal and Structural Analysis of Disk Brake using Finite Element Analysis

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Abstract. The present paper discusses and examine a comparative study of the materials of the carbon ceramic matrix and the gray cast iron disk. This disk brake research is used to develop the braking mechanism of passenger cars. The Ansys package used to determine the distribution of temperature, induced heat flux, equivalent stress and deformation due to heat through the disk brake. To analyze the temperature distribution across the disk using axis-symmetric components, steady state thermal analysis was performed. Further structural analysis is often performed through thermal coupling analysis. Competitive analysis of disk brake material that yields less deformation and equal stress (von mises stress) at low temperature around the disk is feasible. For better validity, both outcomes are compared. Therefore, both findings provide a better understanding of the thermal characteristics of the disk brake rotor and enable the automotive industry to create an optimal and reliable disk brake rotor.

Keywords- Disk Brake Rotor, Circular Groove with lining, CMC, Gray Cast Iron, FEA.

1. Introduction
The initial brake use by means of locomotion control, was for mining skips, subsequently further enhanced by the evolution in railway. But true car brakes were only created with the introduction of gas as a fuel in combustion engines. There has actually been an increase in speed, but safety has been decreased and injuries have thus increased.

Lanchaster was the first person who applied for disk brake patent in 1902. This structure consists of a small brake disk of metal mounted to axel of the wheel. Two friction material components were grasped by the disk when the brakes were applied. However, due to the lack of appropriate materials and hence the inefficient working of the control circuit, the findings were different and disappointing. One of the key steps in the production of the disk brake occurred when Dunlop fitted a Jaguar XK 120 with disk brakes in 1953.

The Finite Element (FE) brake disk models were formed using CATIA and simulated using ANSYS. This system was based on the Finite Element Analysis (FEA). Three separate loading conditions were used to model the brake disks: two static tests (torsion and simulation of lateral strength) and one thermal analysis (simulation of residual stress). Particular attention was paid to the residual stress simulation of the Parietal brake-disk where, due to its nature, a potential problem could arise.

Fig.1. Passenger car braking system
1.1 Operating Principle of the Disk Brake System

The theory is used that the applied force (pressure) acts on the brake pads which come into contact with the moving disk. At this point in time, due to friction with relative motion, it is constrained.

**Working:** As the brakes are used the hydraulically actuated pistons bring the friction pads into contact with the disk, applying the same and opposite forces to the disk. When the brakes are discharged, the rubber sealing ring serves as a return spring and retracts the pistons and the friction pads away from the disk.

![Diagram of disk brake system](https://www.semanticscholar.org/)

Fig. 2. The operating principle of the disk brake system
(Source https://www.semanticscholar.org/)

2. Literature Review

Finite element analysis approaches are becoming the most appropriate and easy way to simulate the performance of a disk brake rotor. The thermal behavior of the brake disk is by no means easy to predict, depending on the existence of the time-dependent heat flux and cooling air flow.

According to **Thuresson, 2004** ¹ “The amount of heat flux flows through each part depends on the material of the disk and pad.” As per the studies conducted by **Koetniyom, 2000** ² “The value of the heat flux calculation is used in the FE model to analyze the resulting temperature distributions.”

Studies conducted by **Swapnil R. Abhang, 2014** ³ “Carbon ceramic matrix disk brake material used to measure normal force, shear strength and piston strength. And also measure the disk brake distance. The basic two-wheeler disk brake model used in Ansys and conducted Thermal Analysis and Modal Analysis also measures deflection and Heat Flux Distribution, Disk Break Model Temperature. This is important to understand the action force and friction force of the new material on the disk brake.”

**Limpert, 1975** ⁴ “has studied the thermal efficiency of a solid disk brake during braking. The heat flux for the disk was derived from the coefficient of friction and heat distribution between the rotor and the pad under uniform pressure loading. Experimental work was carried out to confirm the findings of theoretical estimates. During a series of brake applications, the effects of the experimental work and the theoretical calculations were well associated.”

According to Sheridan et al. 1988 ⁵ “various techniques for the thermal modeling of disk brakes, ranging from a simple axis symmetrical Finite Element model to a complex 3-dimensional Finite Element model. The paper also reviewed the methods used to calculate the thermal boundary conditions of the model. The influence of the energy input and output as well as the material properties, such as thermal conductivity and specific heat, had a major impact on the temperature response. Their results showed that 90% of the heat produced during braking is transferred to the ambient air through convection.”

**Noyes and Vickers** ⁶ “have shown that the temperature field can be predicted with reasonable accuracy by assuming a uniform heat flux. There have been many attempts based on thermal stress analysis to predict structural behavior.”

**Ali Belhocine and Mostefa Bouchetara.2013** ⁷ “examined the thermo-mechanical actions of the dry contact between the brake disk and the pads during the braking process. The simulation strategy is based on the ANSYS11 programming code. In reality, the modeling of the transient temperature in the disk is used to define the geometric design factor of the disk for the installation of the ventilation system in automobiles. The thermal-structural analysis is then used to determine the
deformation formed on the disk and the Von Mises stresses, the distribution of contact pressure in pads.”

3. Research Methodology
This paper is based on the temperature distribution and structural effect of the CMC and Gray Cast iron (GG20) disk brake rotor on static state analysis. Starting with a literature review, a lot of paper and a journal has been read and part of it has been considered in this project. In the meantime, the Coordinate Measuring Machine (CMM) was used to calculate the main co-ordinate of the actual disk brake rotor. CMM was used to achieve precise measurements of the disk brake rotor. Later, the exact dimensions were used to translate 2D and 3D sketches using CATIA.

In the second point, a load analysis was carried out where the heat flux and the convectional heat transfer coefficients were determined. Load analysis determined on the basis of the maximum load of passengers in the standard passenger vehicle. Later, load analysis value was used for finite element analysis.

First the fractional 3D disk brake rotor model was moved to the ANSYS11 finite element program. Thermal study of steady state reactions has been conducted. At this point, the assignment of material properties, loading and meshing of the model was carried out. After completion of the meshing, the model was submitted for review. Finally, the predicted result of the steady state and transient reactions of the thermal analysis was obtained.

3.1 Properties of Disk Brake Materials

3.1.1 Carbon Ceramic Matrix Material
The goal of developing CMCs was to resolve the problems associated with traditional technical ceramics such as alumina, silicon carbide, aluminum nitride, silicon nitride or zirconia. There are various cracks caused by small defects or scratches. These materials easily break under the mechanical or thermo-mechanical loads. On the other hand, the crack resistance is very low in glass. There are number of particles (like as monocrystalline whiskers or platelets) were inserted in the matrix to improve the crack resistance or fracture toughness.

3.1.2 Gray Cast Iron (GG20)
The composition of the grey cast iron disk brake rotor is 3.53 wt carbon percent, 2.04 wt Si (Silicon) percent, 0.63 wt Mg (Manganese) percent, 0.1 wt S (Sulphur) percent, 0.06 wt P (Phosphorus) percent, 0.29 wt chromium percent, 0.79 wt copper percent, 0.011 wt Ti (Titanium) percent, 0.10 wt V (Vanadium) percent, and (Fe) Iron balance. The hard carbide forming metals (Cr, Ti and V) thus total 0.401 wt percent, so that the ratio of 1.97 units of Cu (Copper) to 1 unit of the hard carbide forming metal between the weight of Cu present and the weight of aforesaid hard carbide forming metals.

| S No. | Properties                  | Carbon Ceramic Matrix | Gray Cast Iron(GG20) |
|-------|-----------------------------|-----------------------|----------------------|
| 1.    | Thermal Conductivity, (K)   | 40 w m/ k             | 52 w m/ k            |
| 2.    | Density, (ρ)                | 1800 kg/m³            | 7250 kg / m³        |
| 3.    | Specific heat, (c)          | 0.8 kJ/ kg K          | 0.5 kJ/ kg K        |
| 4.    | Passion ratio, (v)          | 0.32                  | 0.28                 |
| 5.    | Thermal Expansion           | 1.1E-006 C⁻¹          | 4.0 E-006 C⁻¹       |
| 6.    | Thermal stability           | Approx. 1350 °C       | Approx. 700 °C      |
7. Tensile strength  2.4E+008 Pa  2.2E+008 Pa
8. Young’s Modulus  2.4E+0010 Pa  1.1E+0010 Pa
9. Coefficient of friction  0.3  0.2

**Fig. 3.** Dimensions of disk brake rotor with lining

|                  |             |
|------------------|-------------|
| No. of nodes     | 49,436      |
| No. of element   | 23,948      |
| Mass of disk     | 2.4502 Kg   |

**Fig. 4.** Front and Isometric view of disk brake mesh model
Table 2. Input Parameters for Thermal Analysis

|      | Temperature   | Heat Flow   | Convection | Radiation   |
|------|---------------|-------------|------------|-------------|
| Magnitude | 350. °C (ramped) | 6000. W (ramped) |           |             |
| Film Coefficient |                  |             | 530. W/m²·°C (ramped) |           |
| Ambient Temperature |                 |             | 22. °C (ramped) | 22. °C (ramped) |
| Correlation |                   |             | To Ambient |             |
| Emissivity |                 |             |            | 1. (Step applied) |

4. Result

4.1 Thermal and Structural Analysis of CMC Disk with lining

Fig.5. Temperature Distribution

Fig.6. Heat flux of CMC disk with lining

Fig.7. Equivalent (von-mises) Stress

Fig.8. Deformation
4.2 Gray cast Iron Disk

Fig.9. Temperature Distribution
Fig.10. Heat flux of Gray cast Iron disk with lining

Fig.11. Equivalent(von-mises) Stress
Fig.12. Deformation

5. Conclusion

It is inferred on the basis of the current work that the various materials have a different consistency as used for the brake disk.

(i) The overall operating temperature of the gray cast iron is around 700 °C, which is low compared to the 900 °C carbon ceramic.

(ii) The cooling characteristics of ventilated disk rotor are higher than the normal disk brake rotor.

(iii) Ventilated carbon ceramic disk rotor has a low value of deformation compare, then normal CMC disk and gray cast iron disk rotor at the time of maximum load.

(iv) Carbon Ceramic has produced a lower value of equivalent stress compare than gray cast iron at the time of maximum load.

(v) Carbon ceramics have a minimum weight among other materials, and the highest operating temperature is about 900 °C, which is higher than other materials, but the rate of heat loss is higher in ceramics relative to other materials. Thus, we can infer from above that cast iron can be used in the brake disk, which, compared to other materials, will provide mild cooling at low temperatures.

The carbon ceramic has a minimum weight among other material and the maximum operating temperature is about 900 °C which is highest as compare to other material, but the rate of losing the heat is greatest in ceramic as compared to other material. And have minimum deformation therefore,
it is concluded that cast iron may be used in brake disk. This is most suitable to provide moderate cooling at low temperature as compared to another material. Ceramic has excellent cooling characteristics, but it is more expensive than most other materials and cannot be machined quickly. It can also be used in race cars where high temperatures are made.

**Future Scope of Advanced Material** In the present study, it is observed that carbon materials contain high specific rigidity and specific strength due to the result of elemental properties of the carbon atom. This contains several advantages over competing materials. We may have number of examples the use of carbon fiber reinforced plastics such as in aerospace, game and sport equipment’s applications. The carbon composites are also very useful disk brakes for high-temperature aircrafts and formula one car racing. The oxidation process also shielded due to the carbon material properties. Nuclear fission and fusion are also the best technology uses of the carbon composites for the generation of electric power.

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