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Review on the Thermal Response of Disc Brake Systems: An Investigative Study

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Abstract

This study analyzes the structural and thermal performance of disc brakes using finite element analysis (FEA). Various materials, including cast iron, stainless steel, aluminum, Ti–6Al–4V, and aluminum metal matrix composite (AMC), were evaluated for stress, deformation, heat dissipation, and strength. Results show cast iron excels in stress handling, stainless steel in deformation resistance, and aluminum in heat dissipation but lacks strength. Ti-alloy offers promising tribological properties, while AMC reduces rotor weight by 50% and energy consumption by 19%. Optimized designs improve braking efficiency by 15% and reduce weight by 10%. The findings provide insights for future research and automotive brake design improvements.

Keywords: Disc brake, thermal analysis, structural analysis, finite element analysis (FEA), heat dissipation, material performance, stress distribution.

1. INTRODUCTION

One of an automobile's key safety and control systems is the braking system. Bringing down the vehicle's speed from its genuine speed to an ideal one is utilized. Also, it was utilized to hold or stop the vehicles. The use of circle brakes in traveler vehicles and light trucks is a consequence of their various benefits over drum brakes. Most of vehicles have plate brakes introduced. Different circle brake makers utilize two distinct kinds of plate brakes: vented and strong. The caliper is secured to the vehicle's pivot packaging. Rubbing cushions approach the circle when the brakes are locked in, applying equivalent and inverse powers on it. Erosion cushions use contact to change the vehicle's active energy into nuclear power. Two rubbing cushions with their grating surfaces confronting the rotor are utilized in the brake in the ongoing review. Vehicle brake cushions come in four essential assortments: fired, semi-metallic, metallic, and non-asbestos natural. Of them, most of vehicles utilize metallic brake cushions. To make the cushion material, iron, copper, steel, and graphite are normally consolidated and reinforced. The temperature climb of the plate and the grating cushion interface during slowing down influences the stopping mechanism's productivity. Warm mutilation, brake blurring, brake liquid vaporization, brake shouting, and different issues are welcomed on by the temperature increment.

A brake system uses friction to convert the kinetic energy of an automobile in motion into heat. In braking, the friction pad and disc takes away the speed from wheels. In order to halt the vehicle's motion, the brake uses thermal energy, which is then released into the atmosphere. The vehicle's brakes are one of its key control systems. It manages the car in the least amount of time and space. Additionally, it regulates the speed of cars in busy areas and when turning.

Brake Gray cast iron is used to make disc brake rotors, which also include various additives including 3.5% carbon. Grey cast iron has been replaced by a ceramic composite called carbon fiber reinforced carbon–silicon carbide (Cf/C–SiC). To increase mechanical strength, heat transfer, and wear resistance, metallic elements are incorporated.

The disc brake reduces wheel rotation by using callipers to force the pads on the disc. This can be done to keep the wheels stationary or to minimize their speed.

Rotors for disc brakes It is the part that keeps or stops the wheel from rotating. Cast iron is used to make disc brake rotors. Composite materials like carbon fiber or ceramic rotors are employed in high-performance vehicles and racing cars.

2. LITERATURE REVIEW

Thakre, S., et. al, (2016): This paper's main goal is to give a thorough summary of the advancements being made in this area. The goal of the proposed research project is to create and alter a system that maximizes disc brake performance by minimizing the weight and temperature of the disc brake rotor using thermo-mechanical analysis. The suggested disc brake design presents a viable way to increase braking effectiveness by 15% and decrease the disc

brake's total weight by 10%. Numerous techniques of improvement have been presented after extensive research on the disc brake systems' operational issues, rotor material, rotor design, and braking situations. In most situations, structural performance has been shown to be reduced when different ventilation patterns have been investigated to improve heat efficiency. This makes it necessary to design discs with the best possible thermal and structural properties in order to improve disc braking performance without sacrificing strength or other system factors.
Gao, P., et. al., (2016): In this paper, a modified closed-loop coupling disc braking model was laid out utilizing the temperature-subordinate contact coupling solidness and erosion coefficient. Considering the viable temperature range during the real braking process, the proposed modified coupling model could foresee the high-recurrence braking clamor inclination with fulfilled precision. Regarding the abovementioned, the finite element models of the principal braking parts were first settled, and every one of the parts were incorporated and associated with the erosion coefficient and nonexistent springs. Then, at that point, the closed-loop coupling model was exposed to complex eigenvalue examination to decide the braking commotion inclination, and so forth. In conclusion, the compelling temperature range during the real braking process was separated from the thermodynamic recreation. Considering the compelling temperature range, the modified closed-loop coupling model had the option to precisely recognize 87.5% braking commotion propensities and accomplish great consistency with test results.
Sayeed Ahmed, & Algarni, (2017): The ongoing review utilized 3D literature made of maraging steel and added substance assembling to inspect what configuration changes with radial grooves meant for plate brake execution and thermal way of behaving. A few boundary conditions, including rotor speed, braking pressure, and braking time, were utilized to gauge the temperature circulation all through the circle surface. Based on the current aspects, the quantity of radial grooves and plan not set in stone. Through the Immediate Metal Laser Sintering (DMLS) procedure, radial grooves were added to the plate surface to upgrade surface region for ideal intensity dissemination and diminish the strains made during braking. The radial grooves act as cooling channels, effectively cooling the plate surface, which is exposed to outrageous temperature swings during activity. The differences in temperature profile all through the plate with prompted heat transition are analyzed utilizing transient structural and thermal analysis utilizing ANSYS programming. To determine the thermal burdens caused in the circle by sudden temperature changes, FE-based thermo-structural analysis was performed. Thermal weakness and brake circle surface crack can be altogether affected by the greatest temperature and Von Mises pressure in plate brakes without grooves on the circle surface. By adding the radial grooves, it was discovered that the plate brake surface is thermally steady. FE thermal analysis and trial results agree well. DMLS simplifies it to manufacture circle brakes with radial grooves and works on their exhibition at more noteworthy temperatures and speeds. Therefore, DMLS offers a reasonable method for utilizing item improvement technologies.
Jafari, & Akyüz, (2016): The current study uses the Taguchi design of experiments to numerically investigate the best brake disc design with radial vanes while accounting for nine design parameters. The specific wind stream and temperature circulation in the plate are reenacted utilizing the finite element approach, considering close by parts like the cushions, edge, tire, and residue safeguard. It has been discovered that the brake plate cooling is most affected by the expansiveness of the ventilation hole. As the ventilation hole develops from 8 mm to 14 mm, the circle's cooling time drops by 21%. Furthermore, it diminishes by generally 10% when the bend point is expanded from 225 mm to 266 mm and the channel width between two adjoining vanes (reverse of vane numbers from 43 to 30) is expanded. The vented circle's cooling execution is impacted by the balance point, internal and external blade measurements, dust safeguard, ringer connection, and plate material, in diminishing request of importance.

2.1. OBJECTIVES OF THE STUDY

- To utilize a thermal analysis system technique in the design and development of the two-wheeler disc braking system.
- To determine the disc brake's performance using different rotor geometries.
- To enhance disc brake performance.

3. THERMAL STRESS ANALYSIS

The temperature dissemination of these braking plates as a component of time is important to explore the thermal analysis of the circles under cyclic thermal burden conditions. Non-uniform temperature circulations in the rotor are made conceivable by the heat produced at the circle cushion interface during abrupt braking. Somewhere in the range of 300 and 800 C is the scope of heat energy delivered.

The grating coefficient at the brake cushion and plate interface decides the vehicle's result execution as far as braking capacity. The brake plate raises the contact coefficient of the brake cushions as the temperature climbs, which improves the result of braking force. Then again, plate and cushion wear are affected by the higher temperatures. At higher temperatures (about 550 ºC), the brake pads' friction coefficient surprisingly drops, which lowers the amount of braking torque produced. At these temperatures, the chance of thermal cracking increases. Therefore, to guarantee the effective operation of the vehicle's braking system, it is crucial to maintain the brake surface temperatures within reasonable bounds, or below 500 ^{o}C.

3.1. Dissipation of Heat

The different methods of heat transfer through which heat is dispersed like conduction, convection and radiation.

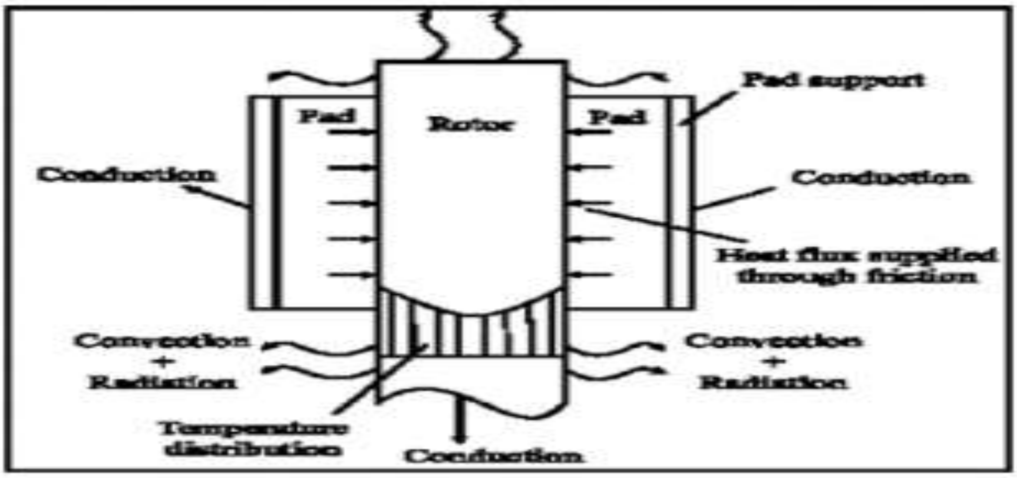

Figure 1: Heat transfer in disc rotor

3.2. Transient Thermal Analysis

Temperature and other related factors that change over the long haul can be determined using transient thermal analysis. Numerous applications, similar to the quenching analysis for heat treatment, require changes in the temperature distribution. The disappointment of such frameworks might be explained by the more noteworthy thermal pressure brought about by the raised temperature distribution.

Table 1: Deformation and stress comparison

Disc	Deformation	Stress
Original Disc	.00369	19
New disc 1	.00382	19
New disc 2	.00568	29
New disc 3	.00534	27
New disc 4	.00351	18
New disc 5	.00585	25

The weight and temperature comparison for different discs is displayed in Table 2.

Table 2: Weight and temperature comparison

Disc	Weight (Kg)	Temperature (C)
Original Disc	.97	123
New disc 1	1.09	123
New disc 2	.88	231
New disc 3	.95	165
New disc 4	1.15	128
New disc 5	.88	95

The outcomes obtained by creators regarding the models, different point burden to both brake plates as displayed in

Table 3: Displacement and stress

Drilled and grooved brake disc	Load (KN)	Displacement (m)	Von Mises Stress (MPa)
Column A	20	.0000193	57.2
Column B	23	.0000230	65.9
Column C	26	.0000269	74.4
Column D	29	.0000288	83.0
Column E	32	.0000326	91.5
Column F	35	.0000355	100.1

Table 4: Stress and displacement

Grooved brake disc	Load (KN)	Displacement (m)	Von Mises Stress (MPa)
Column A	20	.000023	69.2
Column B	23	.000027	86.2
Column C	26	.000030	99.9
Column D	29	.000034	113.7
Column E	32	.000037	125.5
Column F	35	.000041	137.3

For both drilled and grooved disc brakes, as well as grooved-only disc brakes, the data from Tables 3 and 4 show that displacement and Von Mises stress rise with increasing applied loads. Under the same load circumstances, however, the drilled and grooved disc shows reduced displacement and stress values in contrast to the grooved-only disc. This implies that drilled holes enhance heat dissipation and structural integrity, lowering total stress and deformation. The grooved-only disc, on the other hand, is subject to more stress and displacement, suggesting a relatively poorer resilience to thermal and mechanical stressors. Therefore, by reducing stress concentration and deformation under high loads, the combination of drilling and grooving in disc brake design improves performance.

4. PERFORMANCE ANALYSIS

This paper reviews various opening distances in brake rotors and examines the resulting deformation and stress. The deformation in the rotor plate of a disc brake with curved openings is 8.4% higher than in a rotor plate with equivalent circular openings. However, the stress generated in the curved openings of the disc brake rotor is 2.5% lower than that in a rotor with similar circular openings. The study also investigates the impact of changing the opening shape from curved to circular, focusing solely on motorcycle disc brakes.

The research analyzes continuous braking models, observing key parameters such as temperature, operating speed, and the coefficient of friction. The author asserts that laboratory experiments align closely with simulated results in predicting field performance. However, experimental analysis was conducted only on motorcycle brake systems without variations in vehicle speed.

This study further explores the structural and thermal behavior of disc brakes, evaluating stress distribution, temperature distribution, and total deformation. The author concludes that cast iron performs better in terms of stress resistance, while stainless steel offers superior brake performance in terms of deformation. However, the study was limited to only three materials.

Additionally, the paper investigates the structural and thermal characteristics of plate brakes, focusing on heat dissipation and strength. While aluminum demonstrates excellent heat dissipation, its low strength makes it unsuitable for brake rotors. Again, the study considered only three materials.

Finally, this study evaluates the mechanical and tribological properties of laser surface-nitrided Ti-6Al-4V, a material that could be used for braking rotors. According to the author, laser-nitrided Ti-alloy is a practical lightweight substitute for heavier materials due to its tribological properties that offer good performance. However, further evaluation of mechanical and tribological properties is necessary to achieve improved results and address environmental and health concerns.

5. CONCLUSION

Finite element analysis was primarily used in this study to analyze the thermal, mechanical, and structural behavior of disc brakes. Although several ventilation patterns have been considered to improve thermal performance, most of the time they have been shown to result in a reduction in structural performance. This makes it necessary to design discs with the best possible thermal and structural properties in order to improve disc braking performance without sacrificing strength or other system factors. The suggested disc brake design presents a viable way to increase braking effectiveness by 15% and decrease the disc brake's total weight by 10%. Nonetheless, there is much need for advancement in this area of research. In addition to helping the academic community identify study needs for future work, it is expected that this in-depth and comprehensive analysis will assist vehicle manufacturers in creating more efficient disc braking systems for the good of society.

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