A Review on Automobile Disc brake system and Materials

Lakavathu Chinna Balu[*1], Dr. R. Rajendra[2]

[*1]Research Scholar, Mechanical Engineering Department, University College of Engineering (A), Osmania University, Hyderabad, Telangana.

[2]Professor & Head, Mechanical Engineering Department, University College of Engineering (A), Osmania University, Hyderabad, Telangana.

Abstract: The disc brake is a relatively recent innovation in the field of braking technology. In order to slow down a vehicle, it uses friction between a disc rotor and pads to convert the kinetic energy of the wheel into heat. Brake disc and pad friction rises dramatically when applied suddenly, causing a great deal of heat to be produced. High-temperature zones are produced across the disc as a result of the frictional heat generated. The disc may undergo plastic deformation due to localised heating of its surface, which results in a temperature gradient throughout the disc's surface. Overheating, the creation of hotspots, and the occurrence of the thermal judders phenomena all contribute to the disc's eventual failure, which manifests as fractures across the disc's surface. As a consequence, there is a decline in braking efficiency and effectiveness. This article discusses a few specific problems with brake failure caused by overheating and offers solutions to those problems.

Keywords: Disc Brake, Brake Pads, Friction, Heat Dissipation, Thermal Analysis

1. Introduction

To stop or slow down in response to variable road and traffic circumstances, a vehicle needs a functioning braking system. As the name implies, braking systems work by dissipating the momentum of moving vehicles. Different types of brakes accomplish this goal in different ways; friction braking produces heat, whereas regenerative braking generates electricity or compressed air, etc. Not all of the kinetic energy is transformed into the intended form during a braking action; for example, during friction braking, some energy may be lost as vibrations. In [1], we get a quick rundown of the various car braking systems.

Disc brakes and drum brakes are the two most common types of friction brakes. Disc brakes have the potential to self-clean owing to centrifugal forces, and they cool more quickly than drum brakes because of the bigger swept surface and proportionally higher exposure to air flow [2]. Disc brakes are predicted to soon dominate the truck automobile industry [1] and have already been the ubiquitous option for front brakes on vehicles [2].

2. Disc brakes

Because of friction, heat is produced where the disc and pads meet in a disc braking system. Eventually, the heat from the disc dissipates into the surrounding air and metal of the car. Figure 1 [4] depicts a simple disc brake using standard nomenclature. Pads are referred to be "inboard" when they are closer to the vehicle's centre and "outboard" when they are further out. Similarly, the disc's inboard cheek refers to the friction surface closest to the vehicle, while the outboard cheek refers to the disc's opposite side. The term "leading edge" refers to the part of the pad that makes first contact with the disc's surface, while "trailing edge" describes the part that contacts the disc's surface last. The term "inner edge" is used to describe the pad's curved edge with a lower radius, while "outer edge" describes the curved edge with a bigger radius.

2.1 Brake rotor

The brake rotor, also known as the brake disc, spins at the same rate as the wheel since it is attached to the axle. The effectiveness of a disc brake is measured by how quickly its kinetic energy is transformed into thermal energy as the pad slides over the disc. Disc brake performance may be negatively impacted if the disc heats up, hence rapid heat dissipation is crucial for an effective brake design. With the introduction of ventilation in the brake discs, the cooling rate is increased, allowing for optimal performance in demanding situations. There are two main types of brake discs: a) Solid brake discs b) Ventilated brake discs.

The most basic kind of braking disc is a single-piece solid disc. Ventilated discs use vanes, pillars, or both to provide space between the two annular discs that the air flows through. Brake discs with vents allow air to circulate, reducing surface temperature. Brake fade is avoided and disc and pad wear are also slowed by the cooler temperatures. It's possible to make either style with or without a mounting bell. By increasing the disc's surface area and the distance from the friction surface to the axle, mounting bells aid in cooling [3] and shield wheel bearings from the high temperatures produced during braking.

2.1.1 Material used for disc

What kind of material is used for the brake discs is a major factor in the design of the brake discs. Brake discs with a large temperature difference throughout their width are an indication of poor thermal conductivity in the brake material. Because of this, the brake disc's surface will heat up quicker than the disc's body, leading to dissimilar rates of thermal expansion. Brake disc failure is to be anticipated if these thermally produced stresses are too great or if they occur often enough. For this reason, several different modifications are offered for the disc brake assembly.

Gray cast iron with more than 95% pearlite is the most used material for automobile brake rotors [5-6]. Depending on the specific formulation, it may include anywhere from 3.25 percent to 3.70 percent dissolved carbon in its matrix [5]. In addition to being cheap and simple to produce in large quantities, these two factors greatly increase its popularity and explain why it is used so widely. Table 1 displays some of its characteristics [7].

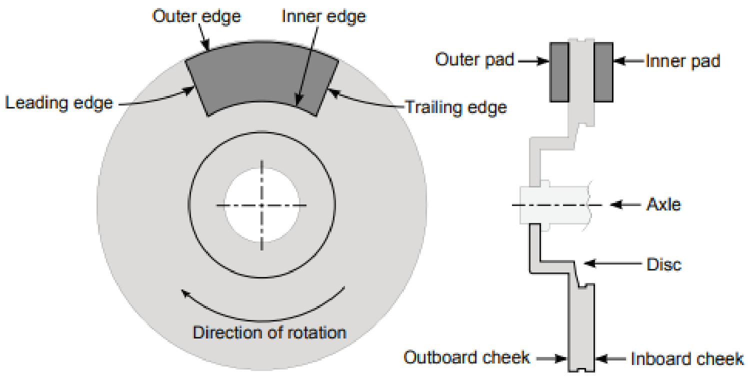

Figure 1: Diagram of disc brake with its different parts [4]

Table 1: Characteristics of Gray Cast Iron

S.No	Properties/Unit	Value
1	Yield Strength (MPa)	214-269
2	Density (kg/m3)	7200
3	Young's Modulus (GPa)	200-211
4	Specific heat capacity (J/kg.K)	498
5	Thermal conductivity (W/m.K)	47.3
6	Thermal expansion coefficient	(× 10-6 1/K) 12.6

Although current disc brake rotors made from cast iron (CI) are effective at stopping vehicles, they are bulkier and produce more pollution when used. There are further drawbacks, such as excessive component wear, brake fade, and judder. The brakes will work poorly, and may even fail, if they are too hot. As a result, there is a need for a less heavy material with lower particulate matter emission.

Carbon fibre was first presented to the public by John Barnard in 1980. Push rods, wishbones, and other composite components were employed in Formula 1 racing cars in the early 1990s. They have been proven effective in many different transportation contexts, including commercial airliners, high-speed rail, and ground-based systems [8]. Graphite and carbon fibre are brought together in these composites. They are robust and resistant to wear and extreme temperatures. Despite these advantages, they have several downsides, such as a low coefficient of friction (0.25) below 450ºC and a high wear rate for brake bads [9]. Due to their high price and lengthy production time, they are seldom used in commercial vehicles. Their expensive isothermal chemical vapour infiltration or liquid-phase impregnation manufacturing methods are the main reasons for this [10].

In 1988, British experts in the railroad sector developed the first C/SiC brake. Their benefits are comparable to those of C/C composites, in that they are both lightweight and resistant to extreme heat. They are durable and have a low rate of wear. Temperature and mechanical qualities may be modified. The 25 mechanical properties they exhibit vary depending on the production techniques used [11]. Since they have a low thermal expansion coefficient and a high resistance to wear, they are effective in minimising judder. Since they have a low Young's modulus, they are helpful in preventing thermal DTV and hot spots while also facilitating more even contact [12]. When compared to C/C composites, which had a variable coefficient of friction, they are superior. They have a consistent coefficient of friction of 0.34. [13]. But there are restrictions on their use. Unfortunately, the chemical vapour infiltration approach is both expensive and potentially dangerous, rendering them unfit for usage in mass-produced passenger vehicles [8]. C/C-Sic composite has been developed as an advanced potential braking material since the early 2000s. Invention for use in brake and clutch facings. This composite is made up of a carbon/carbon-core material with a SiC coating. Because of their low wear rate and high coefficient of friction (0.38), they are preferable [14].

The limitations of this composite stem from its less-than-ideal technique of production. Low deposition rates, high cost, and potential toxicity characterise the chemical vapour infiltration (CVI) technique[15-16]. The RMI procedure (reactive melt infiltration) is expensive. Polymer impregnation/pyrolysis (PIP) and liquid silicon infiltration make up this liquid phase method (LSI). The ceramic technique can't be employed since the carbon fibres are easily damaged by high pressure sintering. For this reason, progress in creating C/C-Sic brake composites has stalled due to the preparation procedure. Warm compaction and in-situ reaction (WCISR) is a method that may be used to deal with these [15]. These composites may be easily incorporated into magnetic levitation vehicles, high-speed trains, and high-performance automobiles using this technology. There is a lack of readily accessible information on how to process this composite, since research into its fabrication is still in its early stages.

2.2 Brake pad

Brake pads have a friction substance bonded to a rigid backing plate. An example of a brake pad and backing plate is shown in Figure 2[4]. To describe the combination of friction material and backing plate, the term "brake pad" is sometimes used. Slots on the pad's face and chamfers on its edges are standard features. Pads may be arranged in a variety of ways, as seen in Figure 8. A pad's slots may have more than one orientation, and there can be several slots altogether. The elimination of squeaks is a primary motivation for using chamfers and slots [17-19]. Convex bending of the pad occurs when its surface temperature is greater than its core temperature [20, 21]. If the material has a slot, it can flex without cracking. Moreover, it provides a means of evasion for the dust that accumulates between the disc and pad surfaces, making it easier to clean.

The development of the brake pad follows ASTM standards, and the brake pad material is comprised of about 17 elements, of which 14 were modified and the rest were kept the same. Copper, iron, and aluminium alloys see the most variation, whereas the other elements are quite stable [22, 23]. The three most common kinds of brake pads are metallic, non-metallic, and organic (but not asbestos-containing) [24]. Liner materials for brake pads typically consist of lubrication, abrasive, reinforcement, filler, and binding agent. The composite structure of the brake pads has many components, each of which performs a different but equally important function, such as enhancing the strength of the pads, achieving a good balance between friction and wear, prolonging the pads' life, or decreasing noise. Molding temperature, moulding time and pressure values, heat treatment temperature, and so on all affect the physical and mechanical characteristics of the brake pad material [25, 26].

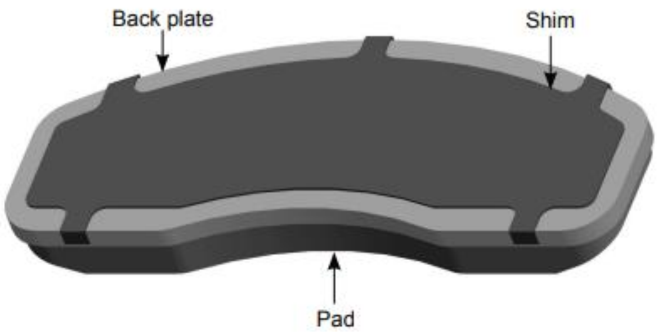

Figure 2: An assembly of back plate, shim and pad

3. FEA of Disc Brake

Researching brake squeal in depth through experimentation is time-consuming and costly. Also, it's possible that an experiment's findings on one kind of braking system won't generalise to another. At this point, new computational and modelling techniques based on the FE approach may give significant insight into predicting and suppressing the squeal noise, which can be used to enhance the design of disc brake components early on. Brake systems may now be accurately represented thanks to the capabilities of FE models, which have a large number of degrees of freedom. More so than experimental approaches, the FE approach gives answers quickly and cheaply.

Kennedy and Ling [27] were the first to publish on the use of thermal analysis in conjunction with mechanical parameters such as sliding contact, wear, thermoelasticity, etc. They hypothesised that there is full macroscopic contact between the pad and disc rotor and that the whole frictional force is transformed into kinetic energy. Thermoelastic instabilities and contact area wear were also considered, with a wear model being developed. The finite element approach was used to successfully describe thermoelastic instabilities, the source of variation in the pad and disc's real contact surface (FEM). They reasoned that if the disc material had more thermal conductivity and heat capacity, the brake discs would have a lower operating temperature. When analysing the temperature change in a disc brake owing to repetitive (fade) braking, Rao et al. [28] also employed the idea of a nonuniform contact surface between the sliding components in the assembly due to thermoelastic instabilities. The findings they found were in good accord with those found experimentally using an inertia dynamometer. Inconsistent energy dispersal between the brake assembly's pot side and finger side led to uneven pad wear.

Pressure distribution in the disc brake was investigated by Day et al. [29], who looked at how different pressures affected thermos-elastic instability-related phenomena such temperature rise, wear, banding, hot spots, and surface damage. To reduce these effects, researchers developed a 2-dimensional axis-symmetric FE model of a 227-millimeter-diameter disc brake and simulated it under 4 seconds of braking. Researchers Dufrenoy and Weichert [30] found that the non-uniform contact between the pad and disc varied with the braking mode (single vs. continuous braking). The efficiency of the braking system and the significant design of the braking system were achieved when the contact surface was examined using impact-contact analysis in conjunction with thermo-mechanical resolution. The use of realistic boundary conditions, such as a non-uniform pressure distribution, is essential for this kind of thermo-mechanical study. The contact force distribution between the disc and pad was calculated by Hohmann et al. [31] using the spare solver ADINA 7.1. To properly design a friction brake system and investigate its sensitivity to pressure variations and deformations, the findings demonstrated the need of a thorough examination of contact between disc and pad. According to Voller et al [32] research, the thermal resistance fluctuation and its sensitivity to clamping pressure may be determined by analysing all heat transfer modes at the disc and wheel carrier contact. As can be seen in Figure 3 [32], all of the many ways that heat might be transferred as a result of friction between the disc and the wheel carrier contribute to the total amount of energy lost as heat during braking.

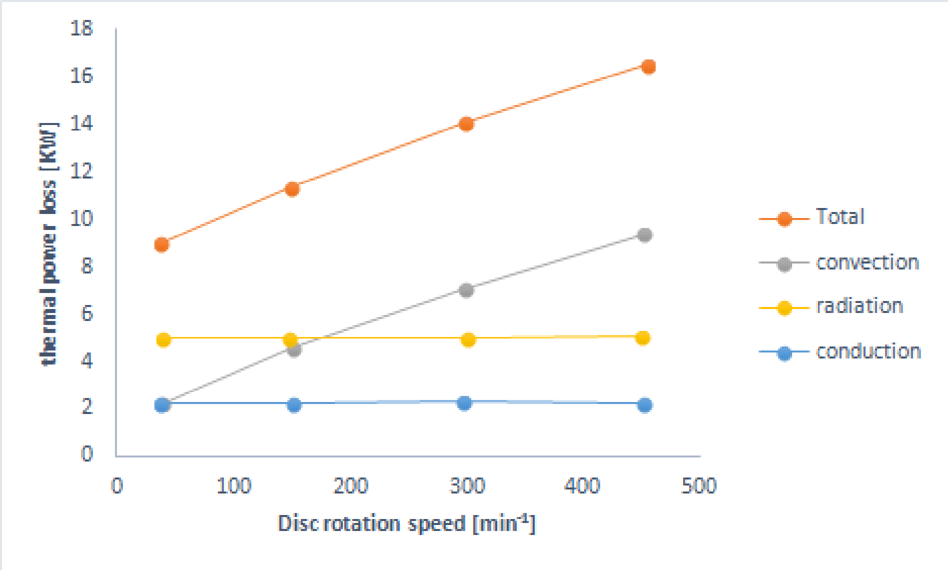

Figure 3: Heat dissipation due to different heat transfer modes [32]

The disc's uneven generation of heat flow causes thermal strains. If the normal pressure (which occurs at the point where the friction material and disc come into contact) were to vary inversely with the disc's radius, this would be a problem that might be mitigated [33]. Disc thermoelastic instability may result from non-uniform variations in this normal pressure. Both temperature gradients and thermal stresses are significantly affected by the ambient pressure. Disc size, the pressure of the hydraulic piston, and the shape of the disc's cross section all have a role in the thermo-mechanical behaviour [34].

4. Recent development in braking materials

Modern brake friction materials have many applications in a variety of fields, including automobile (cars and aircraft), rolling stock and other machinery. Further, it has to be able to withstand extreme temperatures, have a low wear rate, and maintain a consistent temperature. Putting this into action is still challenging. When trying to achieve these criteria and create a new formulation, metal matrix composite friction materials are often supported by experience or trial and error. Making a novel metal matrix composite friction materials requires thinking about what kinds of binders, fibres, fillers, and modifiers would work best. A lot of paper are available on the different materials that are used to develop brake system including Cast iron, asbestos, steel , brass, copper based braking material. But still there is a need to do work on new materials with improved properties as per braking material requirement. One such alternative is metal matrix composite with some fillers like brass and copper as the characterization of this materials have shown prominent result [35].

5. Conclusion

From the review conducted the following conclusion can be with drawn.

- Metal matrix composite materials like ALUMINUM-CARBIDE with brass and copper as fillers should be examined and researched as potential replacements for metal in brake discs.
- Calculating and comparing the mechanical and thermal performance characteristics of the aforementioned materials with those of the commonly used braking material, brake disc, is necessary.
- This research examines the total impact of the coefficient of friction, material density, temperature increase, and heat transfer on brake disc performance. Different vehicle speeds, pedal efforts, coefficients of friction, deceleration rates, and uphill/downhill decelerations must be used to evaluate mechanical and thermal performance.

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