Design and Analysis of a Disc Brake Motor

[1]B.Dayanidhi; [1]G.Santhosh; [1]Ch.Prahalladhudu; [1]B.Krishna Babu; [1]T.Dharmateja and [2]A.Dhanaraj

[1]U.G.Scholars Department of Mech, Nalanda Institute of Engineering & Technology, Sattenapalli
[2]Assistant Professor, Department of Mechanical Nalanda Institute of Engineering & Technology, Sattenapalli.

Abstract: Automobile braking system is one of the most important mechanical devices. The disc brake system is a device for slowing or stopping the rotation of a wheel. Here we are doing a Design and analysis of disk brake Rotor. So in this project we design the disk brake rotor in software name CATIAv5 and analysis is carried out in ansys16.0. In this project we apply the three materials and results are taken for structural and thermal and based upon that we choose the appropriate or suitable material for disk brake rotor.

Keywords: Piston, Aluminium, Grey cast iron, Structural steel.

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I. Introduction

A **disc brake** is a type of brake that uses calipers to squeeze pairs of pads against a disc in order to create friction that retards the rotation of a shaft, such as a vehicle axle, either to reduce its rotational speed or to hold it stationary. The energy of motion is converted into waste heat which must be dispersed. Hydraulic disc brakes are the most commonly used form of brake for motor vehicles but the principles of a disc brake are applicable to almost any rotating shaft.

Compared to drum brakes, disc brakes offer better stopping performance because the disc is more readily cooled. As a consequence discs are less prone to the brake fade caused when brake components overheat. Disc brakes also recover more quickly from immersion (wet brakes are less effective than dry ones).

Most drum brake designs have at least one leading shoe, which gives a servo-effect. By contrast, a disc brake has no self-servo effect and its braking force is always proportional to the pressure placed on the brake pad by the braking system via any brake servo, braking pedal, or lever. This tends to give the driver better "feel" and helps to avoid impending lockup. Drums are also prone to "bell mouthing" and trap worn lining material within the assembly, both causes of various braking problems.

The brake *disc* (or *rotor* in American English) is usually made of cast iron, but may in some cases be made of composites such as reinforced carbon–carbon orceramic matrix composites. This is connected to the *wheel* and/or the *axle*. To retard the wheel, friction material in the form of brake pads, mounted on the brake caliper, is forced mechanically, hydraulically, pneumatically, or electromagnetically against both sides of the disc. Friction causes the disc and attached wheel to slow or stop.

On automobiles, disc brakes are often located within the wheel.

A drilled motorcycle brake disc

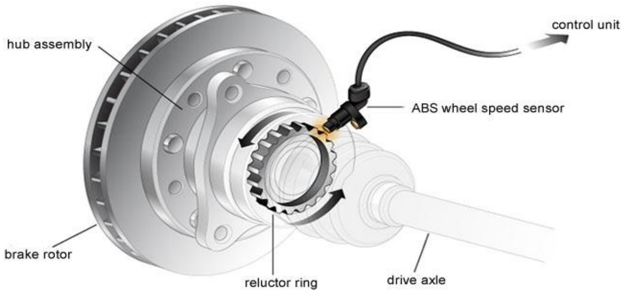
The development of disc-type brakes began in England in the 1890s, but they were not practical or widely available for another 60 years. Successful application required technological progress, which began to arrive in the 1950s, leading to a critical demonstration of superiority at the Le Mans auto race in 1953. The Jaguar racing team won, using disc brake equipped cars, with much of the credit being given to the brakes' superior performance over rivals from firms like Ferrari, equipped with drum brakes. Mass production quickly followed with the 1955 Citroën DS.

Types of Brakes

Brakes are one of the most important safety features on your vehicle. There are different types of brakes, both between vehicles and within a vehicle. The brakes used to stop a vehicle while driving are known as the service brakes, which are either a disc and drum brake. Vehicles also come equipped with other braking systems, including anti-lock and emergency brakes.

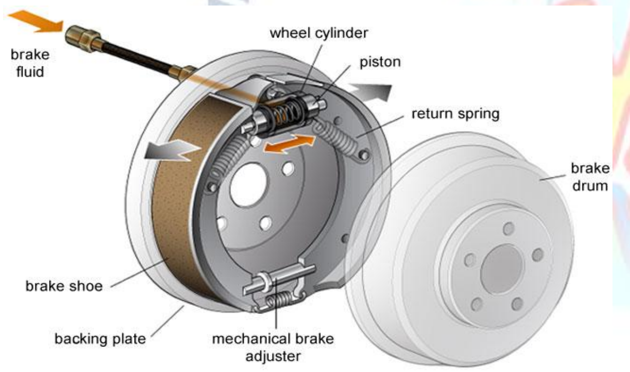
Disc Brakes

Disc brakes consist of a disc brake rotor - which is attached to the wheel - and a caliper, which holds the disc brake pads. Hydraulic pressure from the master cylinder causes the caliper piston to clamp the disc brake rotor between the disc brake pads. This creates friction between the pads and rotor, causing your car to slow down or stop.



Drum Brakes

Drum brakes consist of a brake drum attached to the wheel, a wheel cylinder, brake shoes, and brake return springs. Hydraulic pressure from the master cylinder causes the wheel cylinder to press the brake shoes against the brake drum. This creates friction between the shoes and drum to slow or stop your car.



Emergency Brakes

Vehicles also come equipped with a secondary braking system, known as emergency, or parking brakes. Emergency brakes are independent of the service brakes, and are not powered by hydraulics. Parking brakes use cables to mechanically apply the brakes (usually the rear brake). There are a few different types of emergency brakes, which include: a stick lever located between the driver and passenger seats; a pedal located to the left of the floor pedals; or a push button or handle located somewhere near the steering column. Emergency brakes are most often used as a parking brake to help keep a vehicle stationary while parked. And, yes, they are also used in emergency situations, in case the other brake system fails!

Anti-Lock Brakes

Computer-controlled anti-lock braking systems (ABS) is an important safety feature which is equipped on most newer vehicles. When brakes are applied suddenly, ABS prevents the wheels from locking up and the tires from skidding. The system monitors the speed of each wheel and automatically pulses the brake pressure on and off rapidly on any wheels where skidding is detected. This is beneficial for driving on wet and slippery roads. ABS works with the service brakes to decrease stopping distance and increase control and stability of the vehicle during hard braking.

II. METHODOLOGY

2.1 DEVELOPMENT OF DISC BRAKES

The first caliper-type automobile disc brake was patented by Frederick William Lanchester in his Birmingham factory in 1902 and used successfully on Lanchester cars. However, the limited choice of metals in this period meant that he had to use copper as the braking medium acting on the disc. The poor state of the roads at this time, no more than dusty, rough tracks, meant the copper wore quickly making the system impractical.

The American Crosley Hot Shot is often given credit for the first production disc brakes. For six months in 1950, Crosley built a car with these brakes, then returned to drum brakes. Lack of sufficient research caused reliability problems, such as sticking and corrosion, especially in regions using salt on winter roads. Drum brake conversions for Hot Shots were quite popular. The Crosley disc was a Goodyear development, a caliper type with ventilated rotor, originally designed for aircraft applications.

Chrysler developed a unique braking system, offered from 1949 to 1953. Instead of the disc with caliper squeezing on it, this system used twin expanding discs that rubbed against the inner surface of a cast-iron brake drum, which doubled as the brake housing. The discs spread apart to create friction against the inner drum surface through the action of standard wheel cylinders. Because of the expense, the brakes were only standard on the Chrysler Crown and the Town and Country Newport in 1950. They were optional, however, on other Chryslers, priced around $400, at a time when an entire Crosley Hot Shot retailed for

$935. This four-wheel disc brake system was built by Auto Specialties Manufacturing Company (Ausco) of St. Joseph, Michigan, under patents of inventor H.L. Lambert, and was first tested on a 1939 Plymouth. Chrysler discs were "self energizing," in that some of the braking energy itself contributed to the braking effort. This was accomplished by small balls set into oval holes leading to the brake surface. When the disc made initial contact with the friction surface, the balls would be forced up the holes forcing the discs further apart and augmenting the braking energy. This made for lighter braking pressure than with calipers, avoided brake fade, promoted cooler running, and provided one-third more friction surface than standard Chrysler twelve-inch drums. Today's owners consider the Ausco-Lambert very reliable and powerful, but admit its grabbiness and sensitivity.

Racing breakthrough

Reliable caliper-type disc brakes first appeared in 1953 on the Jaguar C-Type racing car. These brakes helped the company to win the 1953 24 Hours of Le Mans, developed in the UK by Dunlop. That same year, the aluminum bodied Austin-Healey 100S, of which 50 were made, was the first car sold to the public to have disc brakes, fitted to all 4 wheels.

Mass production

The first mass production use of the modern disc brake was in 1955, on the Citroën DS, which featured caliper-type front disc brakes among its many innovations. These discs were mounted inboard near the transmission, and were powered by the vehicle's central hydraulic system. This model went on to sell 1.5 million units over 20 years with the same brake setup.

The Jensen 541, with four-wheel disc brakes, followed in 1956.

Disc brakes were most popular on sports cars when they were first introduced, since these vehicles are more demanding about brake performance. Discs have now become the more common form in most passenger vehicles, although many (particularly light weight vehicles) use drum brakes on the rear wheels to keep costs and weight down as well as to simplify the provisions for a parking brake. As the front brakes perform most of the braking effort, this can be a reasonable compromise.

Many early implementations for automobiles located the brakes on the inboard side of the driveshaft, near the differential, while most brakes today are located inside the wheels. An inboard location reduces the unsprung weight and eliminates a source of heat transfer to the tires.

Historically, brake discs were manufactured throughout the world with a strong concentration in Europe and America. Between 1989 and 2005, manufacturing of brake discs migrated predominantly to China.

Disc brakes in the U.S

After a 10-year hiatus, America built another production automobile equipped with disc brakes - the 1963 Studebaker Avanti(the Bendix system was optional on some of the other Studebaker models). Front disc brakes became standard equipment in 1965 on the Rambler Marlin (the Bendix units were optional on allAmerican Motors' Rambler Classic and Ambassador models), as well as on the Ford Thunderbird, and the Lincoln Continental. A four-wheel disc brake system was also introduced in 1965 on the Chevrolet Corvette Stingray.

Motorcycle Applications

The first motorcycles to use disc brakes were racing vehicles. MV Agusta was the first to offer a front disc brake motorcycle to the public on a small scale in 1965, on their relatively expensive 600 touring motorcycle, using a mechanical brake linkage. In 1969 Honda introduced the more affordable CB750, which had a single hydraulically-actuated front disc brake (and a rear drum brake), and which sold in huge numbers. Disc brakes are now common on motorcycles, mopeds and even mountain bikes.

Brake disk

Front automobile brake with rectangular open slots visible between the disk's friction surfaces

The brake disc is the component of a disc brake against which the brake pads are applied. The material is typically grey iron,[15] a form of cast iron. The design of the disc varies somewhat. Some are simply solid, but others are hollowed out with fins or vanes joining together the disc's two contact surfaces (usually included as part of a casting process). The weight and power of the vehicle determines the need for ventilated discs.[10] The "ventilated" disc design helps to dissipate the generated heat and is commonly used on the more-heavily-loaded front discs.

Beginning in the 1960s on racing cars, it is now common for high-performance cars, motorcycles and even bicycles, to have brakes with drilled holes or slots. This "cross-drilling" is done for a number of reasons: heat dissipation, surface-water dispersal, brake squeal elimination, mass reduction, or marketing cosmetics. An alleged disadvantage of cross drilling for racing or other severe conditions is that the holes might become a source of stress cracks.

Discs may also be slotted, where shallow channels are machined into the disc to aid in removing dust and gas. Slotting is the preferred method in most racing environments to remove gas and water and to deglaze brake pads. Some discs are both drilled and slotted. Slotted discs are generally not used on standard vehicles because they quickly wear down brake pads; however, this removal of material is beneficial to race vehicles since it keeps the pads soft and avoids verifications of their surfaces.

As a way of avoiding thermal stress, cracking and warping, the disc is sometimes mounted in a half loose way to the hub with coarse splines. This allows the disc to expand in a controlled symmetrical way and with less unwanted heat transfer to the hub.

On the road, drilled or slotted discs still have a positive effect in wet conditions because the holes or slots prevent a film of water building up between the disc and the pads. Cross-drilled discs may eventually crack at the holes due to metal fatigue. Cross-drilled brakes that are manufactured poorly or subjected to high stresses will crack much sooner and more severely.

Motorcycles and scooters

Floating disc brake on Kawasaki W800

Radially-mounted brake caliper on aTriumph Speed Triple

Lambretta introduced the first high-volume production use of a single, floating, front disc brake, enclosed in a ventilated pressed-steel shroud and actuated by cable, during 1964 on their range-topping GT200 scooter. The 1969Honda CB750 introduced hydraulic disc brakes on a large scale to the wide motorcycle public, following the lesser known 1965 MV Agusta 600, which had cable-operated mechanical actuation. Unlike car disk brakes that are buried within the wheel, bike disc brakes are in the airstream and have optimum cooling. Although cast iron discs have a porous surface which give superior braking performance, such discs rust in the rain and become unsightly. Accordingly, motorcycle discs are usually stainless steel, drilled, slotted or wavy to disperse rain water. Modern motorcycle discs tend to have a floating design whereby the disc "floats" on bobbins and can move slightly, allowing better disc centering with a fixed caliper. A floating disc also avoids disc warping and reduces heat transfer to the wheel hub. Calipers have evolved from simple single-piston units to two-, four- and even six-piston items.[21] Compared to cars, motorcycles have a higher center of mass: wheelbase ratio, so they experience more weight transfer when braking. Front brakes absorb most of the braking forces, while the rear brake serves mainly to balance the motorcycle during braking. Modern sport bikes typically have twin large front discs, with a much smaller single rear disc. Bikes that are particularly fast or heavy may have vented discs.

Early disc brakes (such as on the early Honda fours and the Norton Commando) sited the calipers on top of the disc, ahead of the fork slider. Although this gave the brake pads better cooling, it is now almost universal practice to site the caliper behind the slider (to reduce the angular momentum of the fork assembly). Rear disc calipers may be mounted above (e.g .BMW R1100S) or below (e.g. Yamaha TRX850) the swinging arm: a low mount is marginally better for CG purposes, while an upper siting keeps the caliper cleaner and better-protected from road obstacles.

A modern development, particularly on inverted ("USD") forks is the radially mounted caliper. Although these are fashionable, there is no evidence that they improve braking performance, nor do they add to the stiffness of the fork. (Lacking the option of a fork brace, USD forks may be best stiffened by an oversize front axle).

Bicycles

Mountain bike front disk brake

Rear disk brake caliper and rotar on mountain brake

Mountain bike disc brakes may range from simple, mechanical (cable) systems, to expensive and powerful, multi-piston hydraulic disc systems, commonly used on downhill racing bikes. Improved technology has seen the creation of the first vented discs for use on mountain bikes, similar to those on cars, introduced to help avoid heat fade on fast alpine descents. Although less common, discs are also used on road bicycles for all-weather cycling with predictable braking, although drums are sometimes preferred as harder to damage in crowded parking, where discs are sometimes bent. Most bicycle brake discs are made of steel. Stainless steel is preferred due to its anti-rust properties. Some lightweight discs are made of titanium or aluminium. Discs are thin, often about 2 mm. Some use a two-piece floating disc style, others use a floating caliper, others use pads that float in the caliper, and some use one moving pad that makes the caliper slide on its mounts, pulling the other pad into contact with the disc. Because the "motor" is small, an uncommon feature of bicycle brakes is that the pads retract to eliminate residual drag when the brake is released. In contrast, most other brakes drag the pads lightly when released so as to minimise initial operational travel.

Other vehicles

Disc brakes are increasingly used on very large and heavy road vehicles, where previously large drum brakes were nearly universal. One reason is that the disc's lack of self-assist makes brake force much more predictable, so peak brake force can be raised without more risk of braking-induced steering or jackknife on articulated vehicles. Another is disc brakes fade less when hot, and in a heavy vehicle air and rolling drag and engine braking are small parts of total braking force, so brakes are used harder than on lighter vehicles, and drum brake fade can occur in a single stop. For these reasons, a heavy truck with disc brakes can stop in about 120% the distance of a passenger car, but with drums stopping takes about 150% the distance.[23] In Europe, stopping distance regulations essentially require disc brakes for heavy vehicles. In the U.S., drums are allowed and are typically preferred for their lower purchase price, despite higher total lifetime cost and more frequent service intervals.

A rail road bogie and disk brake

Still-larger discs are used for railroad cars and some airplanes. Passenger rail cars and light rail vehicles often use disc brakes outboard of the wheels, which helps ensure a free flow of cooling air. However, on some modern passenger rail cars, such as the Amfleet II cars, inboard disc brakes are used. This reduces wear from debris, and also provides protection from rain and snow, which would make the discs slippery, and unreliable. However, there is still plenty of cooling for reliable operation. In contrast, some airplanes have the brake mounted with very little cooling and the brake gets quite hot in a stop, but this is acceptable as there is then time for cooling, and where the maximum braking energy is very predictable.

For automotive use, disc brake discs are commonly manufactured out of a material called grey iron. The SAE maintains a specification for the manufacture of grey iron for various applications. For normal car and light-truck applications, SAE specification J431 G3000 (superseded to G10) dictates the correct range of hardness, chemical composition, tensile strength, and other properties necessary for the intended use. Some racing cars and airplanes use brakes with carbon fiber discs and carbon fiber pads to reduce weight. Wear rates tend to be high, and braking may be poor or grabby until the brake is hot.

Racing

Reinforced carbon brake disc on aFerrari F430 Challenge race car

In racing and very-high-performance road cars, other disc materials have been employed. Reinforced carbon discs and pads inspired by aircraft braking systems such as those used on Concorde were introduced in Formula One by Brabham in conjunction with Dunlop in 1976. Carbon–carbon braking is now used in most top-level motorsport worldwide, reducingunsprung weight, giving better frictional performance and improved structural properties at high temperatures, compared to cast iron. Carbon brakes have occasionally been applied to road cars, by the French Venturi sports car manufacturer in the mid 1990s for example, but need to reach a very high operating temperature before becoming truly effective and so are not well suited to road use. The extreme heat generated in these systems is easily visible during night racing, especially at shorter tracks. It is not uncommon to be able to look at the cars, either live in person or on television and see the brake discs glowing red during application

Ceramic composites

Mercedes Benz AMG carbon ceramic brake

Porsche Carrera S composite ceramic brake

Ceramic discs are used in some high-performance cars and heavy vehicles.

The first development of the modern ceramic brake was made by British engineers working in the railway industry for TGV applications in 1988. The objective was to reduce weight, the number of brakes per axle, as well as provide stable friction from very high speeds and all temperatures. The result was a carbon-fibre-reinforced ceramic process which is now used in various forms for automotive, railway, and aircraft brake applications.

Due to the high heat tolerance and mechanical strength of ceramic composite discs, they are often used on exotic vehicles where the cost is not prohibitive to the application. They are also found in industrial applications where the ceramic disc's light weight and low-maintenance properties justify the cost relative to alternatives. Composite brakes can withstand temperatures that would make steel discs bendable.

Porsche's Composite Ceramic Brakes (PCCB) are siliconized carbon fiber, with very high temperature capability, a 50% weight reduction over iron discs (therefore reducing the unsprung weight of the vehicle), a significant reduction in dust generation, substantially increased maintenance intervals, and enhanced durability in corrosive environments over conventional iron discs. Found on some of their more expensive models, it is also an optional brake for all street Porsches at added expense. It is generally recognized by the bright yellow paintwork on the aluminum six-piston calipers that are matched with the discs. The discs are internally vented much like cast-iron ones, and cross-drilled.

Adjustment mechanism

In automotive applications, the piston seal has a square cross section, also known as a square-cut seal.

As the piston moves in and out, the seal drags and stretches on the piston, causing the seal to twist. The seal distorts approximately 1/10 of a millimeter. The piston is allowed to move out freely, but the slight amount of drag caused by the seal stops the piston from fully retracting to its previous position when the brakes are released, and so takes up the slack caused by the wear of the brake pads, eliminating the need for return springs.[25][26]

In some rear disc calipers, the parking brake activates a mechanism inside the caliper that performs some of the same function.

Disc damage modes

Discs are usually damaged in one of four ways: scarring, cracking, warping or excessive rusting. Service shops will sometimes respond to any disc problem by changing out the discs entirely, This is done mainly where the cost of a new disc may actually be lower than the cost of labour to resurface the old disc. Mechanically this is unnecessary unless the discs have reached manufacturer's minimum recommended thickness, which would make it unsafe to use them, or vane rusting is severe (ventilated discs only). Most leading vehicle manufacturers recommend brake disc skimming (US: turning) as a solution for lateral run-out, vibration issues and brake noises. The machining process is performed in a brake lathe, which removes a very thin layer off the disc surface to clean off minor damage and restore uniform thickness. Machining the disc as necessary will maximise the mileage out of the current discs on the vehicle.

Run-out

Run-out is measured using a dial indicator on a fixed rigid base, with the tip perpendicular to the brake disc's face. It is typically measured about ½ in (12.7 mm) from the outside diameter of the disc. The disc is spun. The difference between minimum and maximum value on the dial is called lateral run-out. Typical hub/disc assembly run-out specifications for passenger vehicles are around 2⁄1000 in (0.0508 mm). Runout can be caused either by deformation of the disc itself or by runout in the underlying wheel hub face or by contamination between the disc surface and the underlying hub mounting surface. Determining the root cause of the indicator displacement (lateral runout) requires disassembly of the disc from the hub. Disc face runout due to hub face runout or contamination will typically have a period of 1 minimum and 1 maximum per revolution of the brake disc.

Discs can be machined to eliminate thickness variation and lateral run-out. Machining can be done in situ (on-car) or off-car (bench lathe). Both methods will eliminate thickness variation. Machining on-car with proper equipment can also eliminate lateral run-out due to hub-face non-perpendicularity.

Incorrect fitting can distort (warp) discs; the disc's retaining bolts (or the wheel/lug nuts, if the disc is simply sandwiched in place by the wheel, as on many cars) must be tightened progressively and evenly. The use of air tools to fasten lug nuts can be bad practice, unless a torque wrench is also used for final tightening. The vehicle manual will indicate the proper pattern for tightening as well as a torque rating for the bolts. Lug nuts should never be tightened in a circle. Some vehicles are sensitive to the force the bolts apply and tightening should be done with a torque wrench.

Often uneven pad transfer is confused for disc warping.[27] In reality, the majority of brake discs which are diagnosed as "warped" are actually simply the product of uneven transfer of pad material. Uneven pad transfer will often lead to a thickness variation of the disc. When the thicker section of the disc passes between the pads, the pads will move apart and the brake pedal will raise slightly; this is pedal pulsation. The thickness variation can be felt by the driver when it is approximately 0.17 mm (0.0067 in) or greater (on automobile discs).

This type of thickness variation has many causes, but there are three primary mechanisms which contribute the most to the propagation of disc thickness variations connected to uneven pad transfer. The first is improper selection of brake pads for a given application. Pads which are effective at low temperatures, such as when braking for the first time in cold weather, often are made of materials which decompose unevenly at higher temperatures. This uneven decomposition results in uneven deposition of material onto the brake disc. Another cause of uneven material transfer is improper break in of a pad/disc combination. For proper break in, the disc surface should be refreshed (either by machining the contact surface or by replacing the disc as a whole) every time the pads are changed on a vehicle. Once this is done, the brakes are heavily applied multiple times in succession. This creates a smooth, even interface between the pad and the disc. When this is not done properly the brake pads will see an uneven distribution of stress and heat, resulting in an uneven, seemingly random, deposition of pad material. The third primary mechanism of uneven pad material transfer is known as "pad imprinting." This occurs when the brake pads are heated to the point that the material begins to break-down and transfer to the disc. In a properly broken in brake system (with properly selected pads), this transfer is natural and actually is a major contributor to the braking force generated by the brake pads. However, if the vehicle comes to a stop and the driver continues to apply the brakes, the pads will deposit a layer of material in the shape of the brake pad. This small thickness variation can begin the cycle of uneven pad transfer.

Once the disc has some level of variation in thickness, uneven pad deposition can accelerate, sometimes resulting in changes to the crystal structure of the metal that composes the disc in extreme situations. As the brakes are applied, the pads slide over the varying disc surface. As the pads pass by the thicker section of the disc, they are forced outwards. The foot of the driver applied to the brake pedal naturally resists this change, and thus more force is applied to the pads. The result is that the thicker sections see higher levels of stress. This causes an uneven heating of the surface of the disc, which causes two major issues. As the brake disc heats unevenly it also expands unevenly. The thicker sections of the disc expand more than the thinner sections due to seeing more heat, and thus the difference in thickness is magnified. Also, the uneven distribution of heat results in further uneven transfer of pad material. The result is that the thicker-hotter sections receive even more pad material than the thinner-cooler sections, contributing to a further increase in the variation in the disc's thickness. In extreme situations, this uneven heating can actually cause the crystal structure of the disc material to change. When the hotter sections of the discs reach extremely high temperatures (1,200–1,300 °F or 649–704 °C), the metal can undergo a phase transformation and the carbon which is dissolved in the steel can precipitate out to form carbon-heavy carbide regions known as cementite. This iron carbide is very different from the cast iron the rest of the disc is composed of. It is extremely hard, very brittle, and does not absorb heat well. After cementite is formed, the integrity of the disc is compromised. Even if the disc surface is machined, the cementite within the disc will not wear or absorb heat at the same rate as the cast iron surrounding it, causing the uneven thickness and uneven heating characteristics of the disc to return.

Scarring

Scarring (US: Scoring) can occur if brake pads are not changed promptly when they reach the end of their service life and are considered worn out. Once enough of the friction material has worn away, the pad's steel backing plate (for glued pads) or the pad retainer rivets (for riveted pads) will bear directly upon the disc's wear surface, reducing braking power and making scratches on the disc. Generally a moderately scarred / scored disc, which operated satisfactorily with existing brake pads, will be equally usable with new pads. If the scarring is deeper but not excessive, it can be repaired by machining off a layer of the disc's surface. This can only be done a limited number of times as the disc has a minimum rated safe thickness. The minimum thickness value is typically cast into the disc during manufacturing on the hub or the edge of the disc. In Pennsylvania, which has one of the most rigorous auto safety inspection programs in North America, an automotive disc cannot pass safety inspection if any scoring is deeper than .015 inches (0.38 mm), and must be replaced if machining will reduce the disc below its minimum safe thickness.

To prevent scarring, it is prudent to periodically inspect the brake pads for wear. A tire rotation is a logical time for inspection, since rotation must be performed regularly based on vehicle operation time and all wheels must be removed, allowing ready visual access to the brake pads. Some types of alloy wheels and brake arrangements will provide enough open space to view the pads without removing the wheel. When practical, pads that are near the wear-out point should be replaced immediately, as complete wear out leads to scarring damage and unsafe braking. Many disc brake pads will include some sort of soft steel spring or drag tab as part of the pad assembly, which is designed to start dragging on the disc when the pad is nearly worn out. The result is a moderately loud metallic squealing noise, alerting the vehicle user that service is required, and this will not normally scar the disc if the brakes are serviced promptly. A set of pads can be considered for replacement if the thickness of the pad material is the same or less than the thickness of the backing steel. In Pennsylvania, the standard is 1/32".

Cracking

Cracking is limited mostly to drilled discs, which may develop small cracks around edges of holes drilled near the edge of the disc due to the disc's uneven rate of expansion in severe duty environments. Manufacturers that use drilled discs as OEM typically do so for two reasons: appearance, if they determine that the average owner of the vehicle model will prefer the look while not overly stressing the hardware; or as a function of reducing the unsprung weight of the brake assembly, with the engineering assumption that enough brake disc mass remains to absorb racing temperatures and stresses. A brake disc is a heat sink, but the loss of heat sink mass may be balanced by increased surface area to radiate away heat. Small hairline cracks may appear in any cross drilled metal disc as a normal wear mechanism, but in the severe case the disc will fail catastrophically. No repair is possible for the cracks, and if cracking becomes severe, the disc must be replaced. These cracks occur due to the phenomenon of low cycle fatigue as a result of repeated hard braking.[28]

Rusting

The discs are commonly made from cast iron and a certain amount of surface rust is normal. The disc contact area for the brake pads will be kept clean by regular use, but a vehicle that is stored for an extended period can develop significant rust in the contact area that may reduce braking power for a time until the rusted layer is worn off again. Rusting can also lead to disc warping when brakes are re-activated after storage because of differential heating between unrusted areas left covered by pads and rust around the majority of the disc area surface. Over time, vented brake discs may develop severe rust corrosion inside the ventilation slots, compromising the strength of the structure and needing replacement.

Caliper

GM disc brake caliper (twin-piston, floating) removed from its mounting for changing pads

The brake caliper is the assembly which houses the brake pads and pistons. The pistons are usually made of plastic,aluminium or chrome-plated steel.

Calipers are of two types, floating or fixed. A fixed caliper does not move relative to the disc and is thus less tolerant of disc imperfections. It uses one or more pairs of opposing pistons to clamp from each side of the disc, and is more complex and expensive than a floating caliper.

A floating caliper (also called a "sliding caliper") moves with respect to the disc, along a line parallel to the axis of rotation of the disc; a piston on one side of the disc pushes the inner brake pad until it makes contact with the braking surface, then pulls the caliper body with the outer brake pad so pressure is applied to both sides of the disc. Floating caliper (single piston) designs are subject to sticking failure, caused by dirt or corrosion entering at least one mounting mechanism and stopping its normal movement. This can lead to the caliper's pads rubbing on the disc when the brake is not engaged or engaging it at an angle. Sticking can result from infrequent vehicle use, failure of a seal or rubber protection boot allowing debris entry, dry-out of the grease in the mounting mechanism and subsequent moisture incursion leading to corrosion, or some combination of these factors. Consequences may include reduced fuel efficiency, extreme heating of the disc or excessive wear on the affected pad. A sticking front caliper may also cause steering vibration.

Another type of floating caliper is a swinging caliper. Instead of a pair of horizontal bolts that allow the caliper to move straight in and out respective to the car body, a swinging caliper utilizes a single, vertical pivot bolt located somewhere behind the axle centerline. When the driver presses the brakes, the brake piston pushes on the inside piston and rotates the whole caliper inward, when viewed from the top. Because the swinging caliper's piston angle changes relative to the disk, this design uses wedge-shaped pads that are narrower in the rear on the outside and narrower on the front on the inside.

Various types of brake calipers are also used on bicycle rim brakes.

Pistons and cylinders

The most common caliper design uses a single hydraulically actuated piston within a cylinder, although high performance brakes use as many as twelve. Modern cars use different hydraulic circuits to actuate the brakes on each set of wheels as a safety measure. The hydraulic design also helps multiply braking force. The number of pistons in a caliper is often referred to as the number of 'pots', so if a vehicle has 'six pot' calipers it means that each caliper houses six pistons.

Brake failure can result from failure of the piston to retract, which is usually a consequence of not operating the vehicle during prolonged storage outdoors in adverse conditions. On high-mileage vehicles, the piston seals may leak, which must be promptly corrected.

Brake pads

Brake pads are designed for high friction with brake pad material embedded in the disc in the process of bedding while wearing evenly. Friction can be divided into two parts. They are: adhesive and abrasive.

Depending on the properties of the material of both the pad and the disc and the configuration and the usage, pad and disc wear rates will vary considerably. The properties that determine material wear involve trade-offs between performance and longevity.

The brake pads must usually be replaced regularly (depending on pad material, and drivestyle), and some are equipped with a mechanism that alerts drivers that replacement is needed, such as a thin piece of soft metal that rubs against the disc when the pads are too thin causing the brakes to squeal, a soft metal tab embedded in the pad material that closes an electric circuit and lights a warning light when the brake pad gets thin, or an electronic sensor.

Generally road-going vehicles have two brake pads per caliper, while up to six are installed on each racing caliper, with varying frictional properties in a staggered pattern for optimum performance.

Early brake pads (and linings) contained asbestos, producing dust which should not be inhaled. Although newer pads can be made of ceramics, Kevlar, and other plastics, inhalation of brake dust should still be avoided regardless of material.

Brake Squeal

Sometimes a loud noise or high pitched squeal occurs when the brakes are applied. Most brake squeal is produced by vibration (resonance instability) of the brake components, especially the pads and discs (known as *force-coupled excitation*). This type of squeal should not negatively affect brake stopping performance. Techniques include adding chamfer pads to the contact points between caliper pistons and the pads, the bonding insulators (damping material) to pad backplate, the brake shims between the brake pad and pistons, etc. All should be coated with an extremely high temperature, high solids lubricant to help reduce annoying squeal. This allows the metal to metal parts to move independently of each other and thereby eliminate the buildup of energy that can create a frequency that is heard as brake squeal, groan, or growl. Cold weather combined with high early-morning humidity (dew) often worsens brake squeal, although the squeal generally stops when the lining reaches regular operating temperatures.

Dust on the brakes may also cause squeal and commercial brake cleaning products are designed to remove dirt and other contaminants.

Some lining wear indicators, located either as a semi-metallic layer within the brake pad material or with an external "sensor", are also designed to squeal when the lining is due for replacement. The typical external sensor is fundamentally different from the noises described above (when the brakes are applied) because the wear sensor noise typically occurs when the brakes are not used.

Brake Judder

Brake judder is usually perceived by the driver as minor to severe vibrations transferred through the chassis during braking. The judder phenomenon can be classified into two distinct subgroups: *hot* (or *thermal*), or *cold* judder.

Hot judder is usually produced as a result of longer, more moderate braking from high speed where the vehicle does not come to a complete stop. It commonly occurs when a motorist decelerates from speeds of around 120 km/h (74.6 mph) to about 60 km/h (37.3 mph), which results in severe vibrations being transmitted to the driver. These vibrations are the result of uneven thermal distributions, or *hot spots*. Hot spots are classified as concentrated thermal regions that alternate between both sides of a disc that distort it in such a way that produces a sinusoidal waviness around its edges. Once the brake pads (friction material/brake lining) comes in contact with the sinusoidal surface during braking, severe vibrations are induced, and can produce hazardous conditions for the person driving the vehicle.

Cold judder, on the other hand, is the result of uneven disc wear patterns or disc thickness variation (DTV). These variations in the disc surface are usually the result of extensive vehicle road usage. DTV is usually attributed to the following causes: waviness and roughness of disc surface, misalignment of axis (runout), elastic deflection, wear and friction material transfers.

III. ANALYSIS

3.1 INTRODUCTION TO FINITE ELEMENT ANALYSIS

The basic concept in fem is that the body or structure may be divided into smaller elements of finite dimensions called “Finite Elements”. The original body or the structure is then considered as an assemblage of these elements connected at a finite number of joints called “nodes” or “nodal points”. Simple functions are chosen to approximate the displacements over each finite element. Such assumed functions are called “shape functions”. This will represent the displacement with in the element in terms of the displacement at the nodes of the elements.

The Finite Element method is a mathematical tool for solving ordinary and partial differential equation because it is a numerical tool, it has the ability to solve the complex problem that can be represented in differential equation from. The application of FEM are limitless as regards the solution of practical design problems.

Due to high cost of computing power of years gone by, FEM has a history of being used to solve complex and cost critical problems.

Now a days, even the most simple of products rely on the finite element method for design evaluation. This is because contemporary design problems usually cannot be solved as accurately & cheaply using any other method that is currently available. Physical testing was the norm in the years gone by, but now it is simply too expensive and time consuming also.

3.2 BASIC CONCEPTS:

The finite element method is based on the idea of building a complicated object with simple blocks or driving a complicated object into small and manageable pieces. Application of this simple idea can be found everywhere in everyday life as well as engineering. The philosophy of FEA can be explained with a small example such as measuring the area of a circle.

Area of one triangle: Si=1/2*R2*sin θI.

Area of the circle: SN=1/2*R2*N*Sin (2∏/N) →∏R2 as N→∞.

Where N= total number of triangles (elements)

If one needs to evaluate the area of the circle without using the conventional formula, one of the approaches could be to divide the above area into a number of equal segments. The area of each triangle multiplied by the number of such segments gives the total area of the circle

3.3 FEA:

Finite Element Analysis was first developed for use in the aerospace and nuclear industries where the safety of the structures is critical. Today, the growth in usage of the method is directly attributable to the rapid advances in computer technology in recent years. As a result, commercial finite element packages exist that are capable of solving the most sophisticated problems, not just in structural analysis. But for a wide range of applications such as steady state and transient temperature distributions, fluid flow simulations and also simulation of manufacturing processes such as injection moulding and metal forming.

FEA consists of a computer model of a material or design that is loaded and analysed for specific results. It is used in new product design, and existing product refinement. A design engineer shall be able to verify the proposed design, which is intended to meet the customer requirements prior to the manufacturing. Things such as, modifying the design of an existing product or structure in order to qualify the product or structure for a new service condition. Can also be accomplished in case of structural failure, FEA may be used to help determine the design modifications to meet the new condition.

Mathematically, the structure to be analysed is subdivided into a mesh of finite sized elements of simple shape. Within each element, the variation of displacement is assumed to be determined by simple polynomial shape functions and nodal displacements. Equations for the strains and stresses are developed in terms of the unknown nodal displacements. From this, the equations of the equilibrium are assembled in a matrix from which can be easily be programmed and solved on a computer. After applying the appropriate boundary conditions, the nodal displacements are found by solving the matrix stiffness equation. Once the nodal displacements are known, element stresses and strains can be calculated.

3.4 DISCRITIZATION OF THE DOMAIN:

The task is to divide the continuum under study into a number of subdivisions called element. Based on the continuum it can be divided into line or area or volume elements.

3.5 APPLICATION OF BOUNDARY CONDITIONS:

From the physics of the problem we have to apply the field conditions i.e. loads and constraints, which will help us in solving for the unknowns.

3.6 VIEWING THE RESULTS:

After the completion of the solution we have to review the required results.

The first two steps of the above said process is known as pre-processing stage, third and fourth are the processing stage and the final step is known as post-processing stage.

3.7 ANSYS INTRODUCTION:

The ANSYS program is self-contained general purpose finite element program developed and maintained by Swason analysis systems Inc .the program contain many routines, all inter related and all for main purpose of achieving a solution to an engineering problem by finite element method.

The ANSYS program has a compressive graphical user interface (GUI) that gives users easy, interactive access to program functions, commands, documentation and reference material. An intuitive menu system helps users navigate through the ANSYS program. Users can input data using a mouse, a keyboard, or a combination of both. A graphical user interface throughout the program, to guide new users through the learning process and provide more experienced users with multiple windows, pull-down menus, dialog boxes, tool bar and online documentation.

3.8 ORGANIZATION OF THE ANSYS PROGRAM

Begin level acts as a gateway into and out of the ANSYS program. It is also used for certain

Global program controls such as changing the job name, clearing (zeroing out) the database, and copying binary files. When we first enter the program, we at the begin level.

At the processor level, several processors are available; each processor is a set of functions that perform a specific analysis task. For example, the general preprocessor (PREP7) is where we build the model, the solution processor (SOLUTION) is where we apply loads and obtain the solution, and the general postprocessor(POST1) is where we evaluate the results and obtain the solution. An additional postprocessor (POST26), enables we to evaluate solutions results at specific points in the model as a function of time.

3.9 PERFORMING A TYPICAL ANSYS ANALYSIS

The ANSYS program has many finite element analysis capabilities, ranging from a simple, linear, static analysis to a complex, nonlinear, transient dynamic analysis. The analysis guide manuals in the ANSYS documentation set describe specific procedures for performing analysis for different engineering disciplines.

3.10 PRE-PROCESSOR

The input data for an ANSYS analysis are prepared using a preprocessor. The general preprocessor (PREP 7) contains powerful solid modelling and mesh generation capabilities, and is also used to define all other analysis data with the benefit of data base definition and manipulation of analysis data. Parametric input, user files, macros and extensive online documentation are also available, providing more tolls and flexibility for the analyst to define the problem. Extensive graphics capability is available throughout the ANSYS program, including isometric, perceptive, section, edge and hidden-line displays of three-dimensional structures-y graphs of input quantities and results, and contour displays of solution results.

3.11 POST PROCESSOR:

Post processing means the results of an analysis. It is probably the most important step in the analysis, because we are trying to understand how the applied loads affects the design, how food your finite element mesh is, and so on.

The analysis results are reviewed using post processors, which have the ability to display distorted geometries, stress and strain contours, flow fields, safety factor contours, contours of potential field results, vector field displays mode shapes and time history graphs. The post processor can also be used for algebraic operations, database manipulators, differentiation and integration of calculated results. Response spectra may be generated from dynamic analysis. Results from various loading may be harmonically loaded axis metric structures.

3.12 MESHING:

Before meshing the model and even before building the model, it is important to think about whether a free mesh or a mapped mesh is appropriate for the analysis. A free mesh has no restrictions in terms of element shapes and has no specified pattern applied to it.

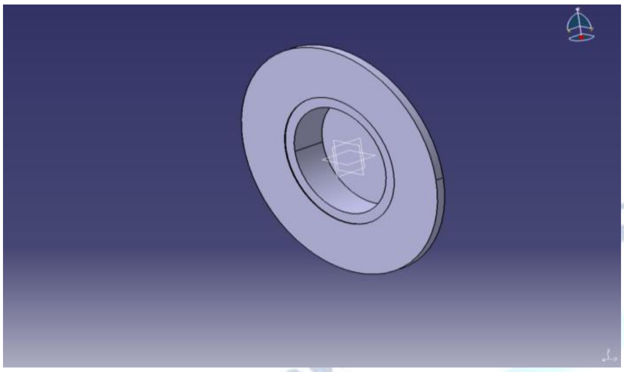
Compare to a free mesh, a mapped mesh is restricted in terms of the element shape it contains and the pattern of the mesh. A mapped area mesh contains either quadrilateral or only triangular elements, while a mapped volume mesh contains only hexahedron elements. If we want this type of mesh, we must build the geometry as series of fairly regular volumes and/or areas that can accept a mapped mesh.

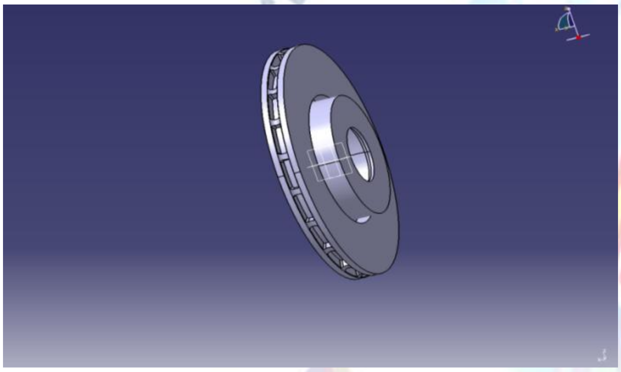
3.13 STRUCTURAL STATIC ANALYSIS:

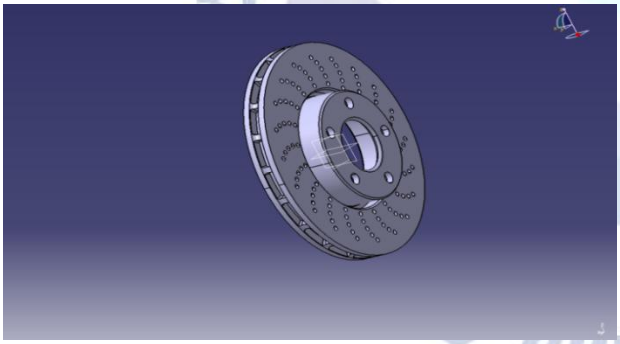
A static analysis calculates the effects of study loading conditions on a structure, while ignoring inertia and damping effects, such as those caused by time varying loads. A static analysis can however include steady inertia loads and time varying loads that can be approximated as static equivalent loads. Static analysis is used to determine the displacements, stresses, strains and forces in structures or components caused by loads that do not induce significant inertia and damping effects. Steady loading and response conditions are assumed, i.e. the loads and the structure's responses are assumed to vary slowly with respect to time.

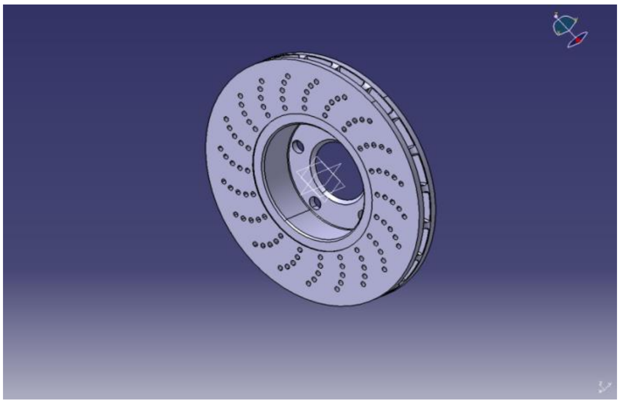
IV.RESULTS AND DISCUSSION

4.1 DESIGN OF DISK BRAKE ROTOR







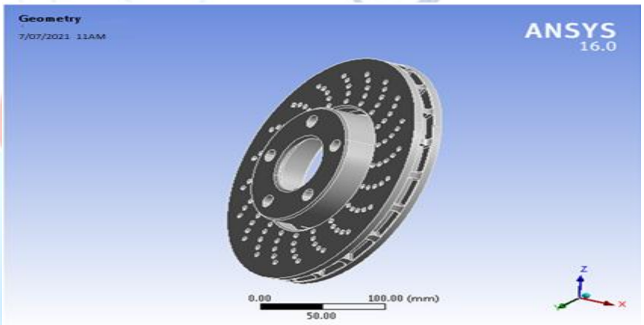


4.2 STRUCTURAL ANALYSIS

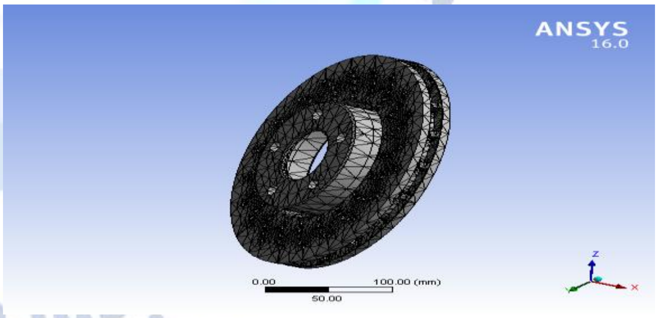
Table :4.1 PROPERTIES OF MATERIALS USED

PROPERTIES	MATERIAL 1	MATERIAL 2	MATERIAL 3
DENSITY, ϱ	7100 kg/m3	2765.2 kg/m3	2820.6 kg/m3
YOUNGS MODULUS,E	125 GPA	98.5 GPA	113.76 GPA
THERMAL CONDUCTIVITY, k	54 W/m K	181.65 W/m K	147.95 W/m K
SPECIFIC HEAT. Cp	586 J/Kg.K	836.8 J/Kg.K	828.43 J/Kg.K
POSSION'S RATIO, υ	0.25	0.33	0.33
COEFFICIENT OF EXPANSION, α	8.1*10-6/0K	17.5*10-6/0K	16.9*10-6/0K

Imported model

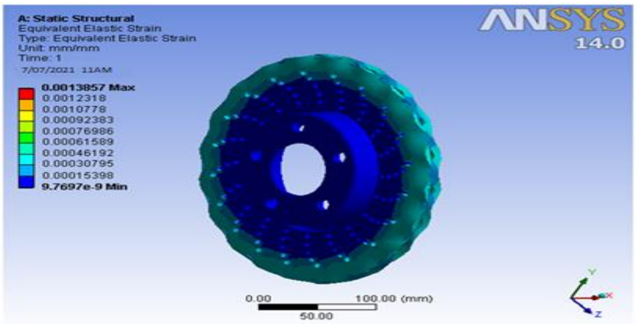


Meshed model

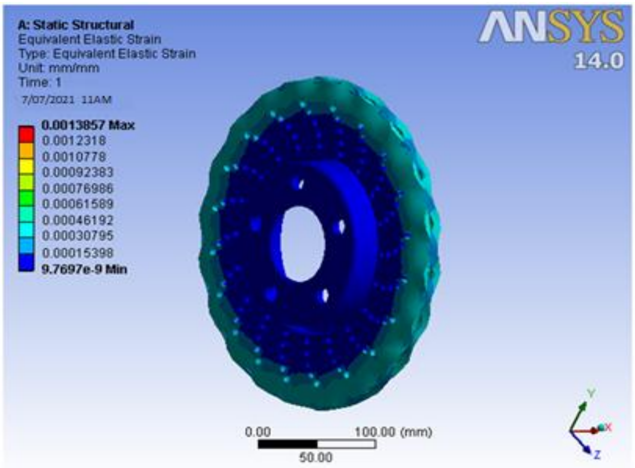


Grey Cast iron

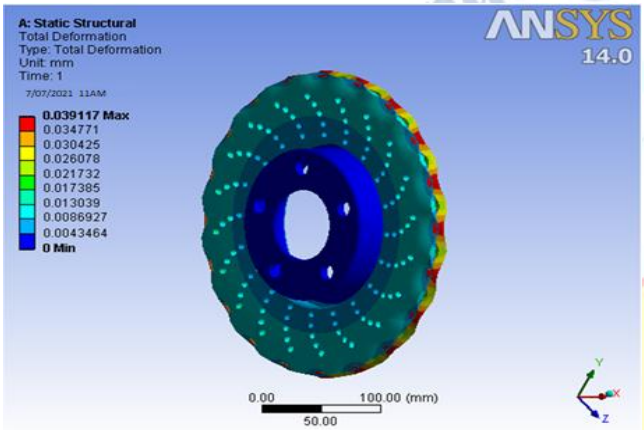
Strain



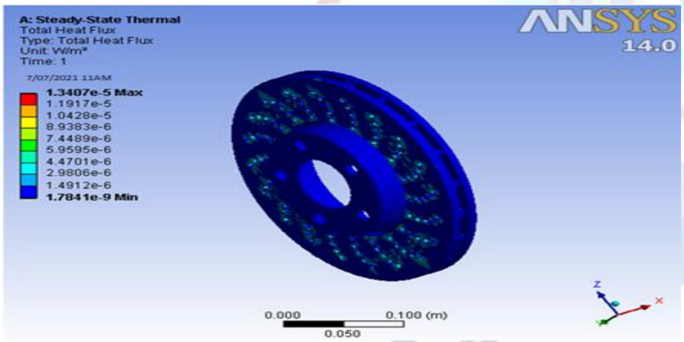
Stress



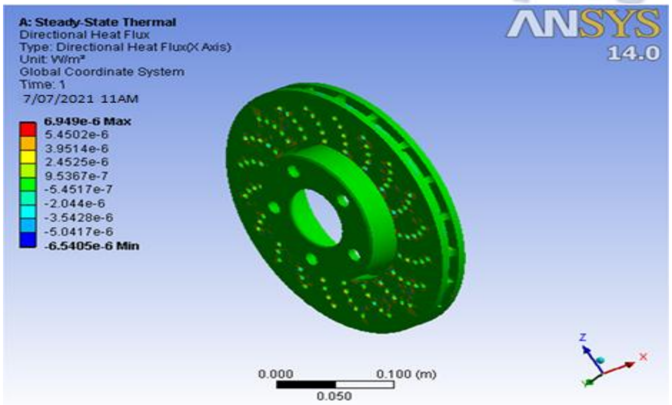
Displcement



Total heat flux

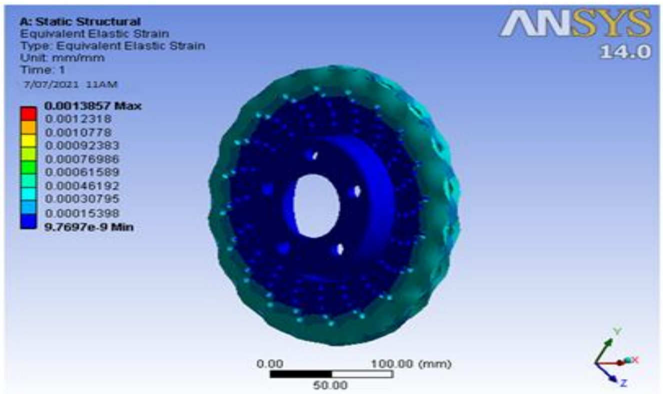


Directional heat flux

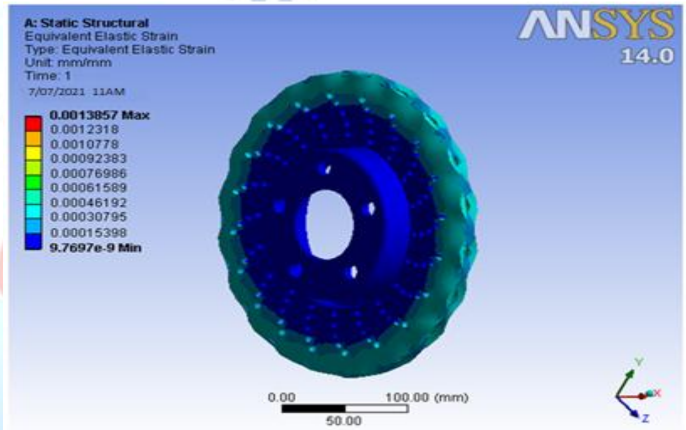


Al-mmc1

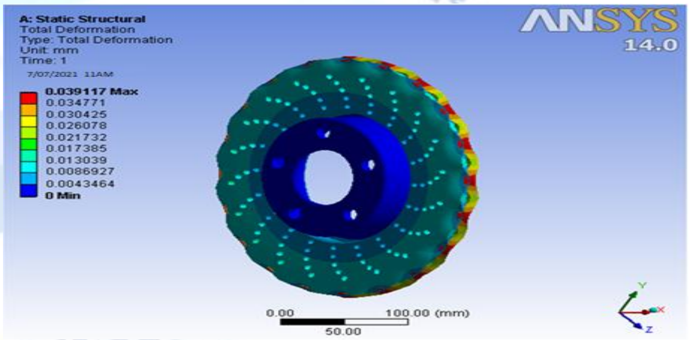
Strain



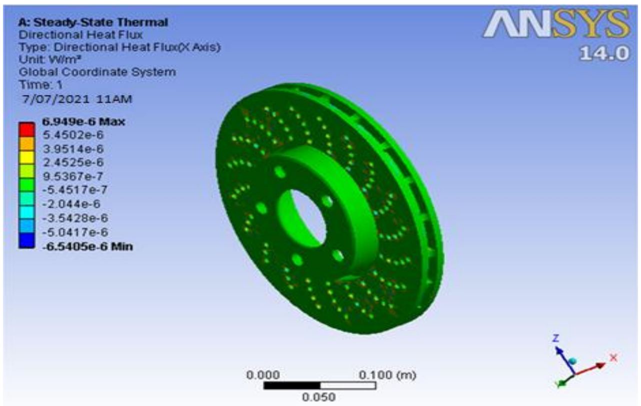
Stress



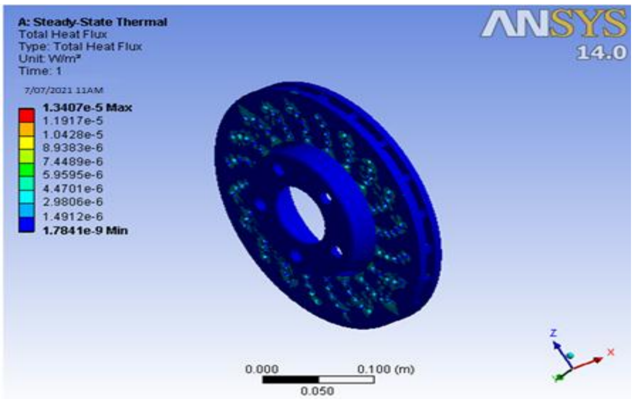
Displcement



Directional heat flux

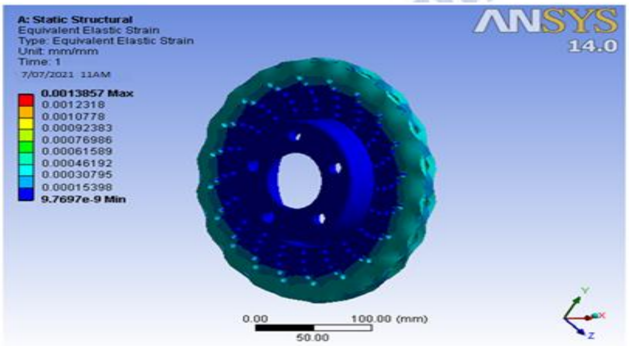


Total heat flux

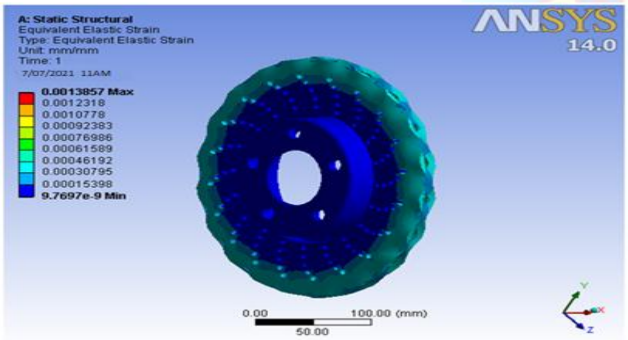


Al-mmc2

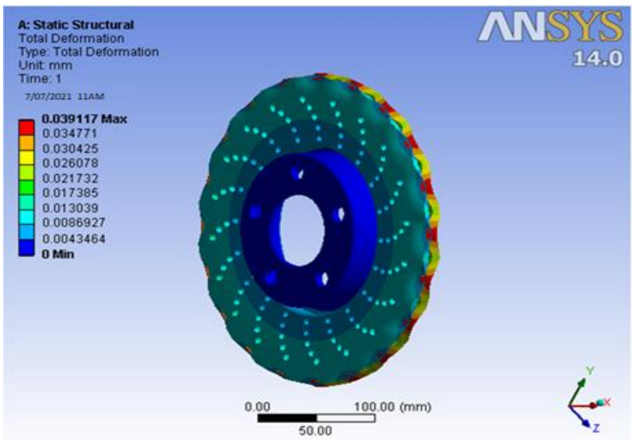
Strain



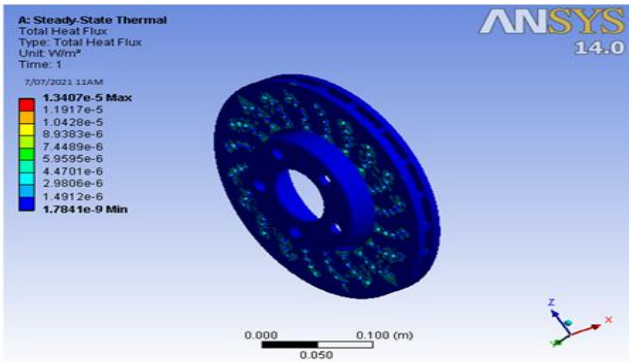
Stress



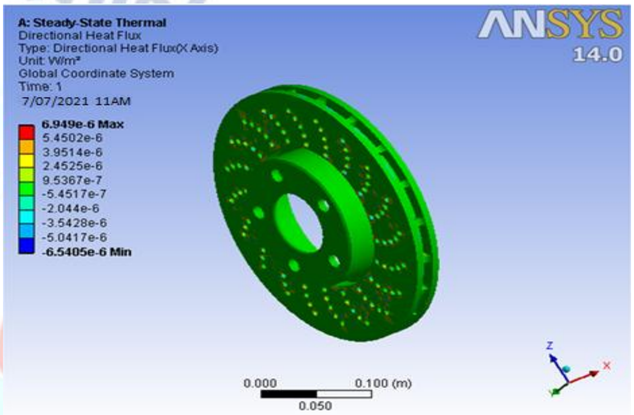
Displacement



Total heat flux



Directional heat flux



V. RESULTS AND CONCLUSION

Material	Stress (Mpa)	Strain (mm/mm)	Deformation (mm)	Total heat flux (W/m2)	Directional heat flux (W/m2)
Grey cast iron	0.013857	173.01	0.039117	1.3407e-5	6.949e-5
Al-mmc 1	0.00171	168.19	0.049418	2.2731e-5	4.4926e-5
Al-mmc 2	0.00171	168.19	0.049418	4.4926e-5	2.2731e-5

From above results it is concluded that the results obtained for stress for three material are 173.01 , 168.19 , 168.19 respectively and the results obtained for total heat flux for three material is 1.307 E-5 4.4926E-5 respectively .So from above results it is concluded that the Al-MMC1 Material is best suitable for disc brake rotar.

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