1.1 INTRODUCTION

One of the most important control systems of an automobile is **Brake system**. They are required to stop the vehicle within the smallest possible distance and it is done by converting kinetic energy of the vehicle into heat energy which is dissipated into atmosphere.

The main requirements of brakes are given below:-

- The brakes must be strong enough to stop the vehicle within the minimum possible distance in an emergency. But this should also be consistent with safety. The driver must have a proper control over the vehicle during emergency braking and the vehicle must not skid.

- The brakes must have good antifade characteristics and their effectiveness should not decrease with constant prolonged application.

The actual stopping distance of vehicle while braking depends on the following factors:-

1. Vehicle speed
2. Condition of the road surface
3. Condition of tyre
4. Coefficient of friction between the tyre and the road surface
5. Coefficient of friction between the brake drum/disc and brake lining pad
6. Braking force applied by the driver
1.2 HISTORY

Disc-style brakes development and use began in England in the 1890s. The first caliper-type automobile disc brake was patented by Frederick William Lanchester in his Birmingham, UK factory in 1902 and used successfully on Lanchester cars. However, the limited choice of metals in this period meant that it 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 that the copper wore quickly making the disc brake system non-viable. It took another half century for his innovation to be widely adopted.

Modern-style disc brakes first appeared on the low-volume Crosley Hotshot in 1949, although they had to be discontinued in 1950 due to design problems. Reliable modern disc brakes were developed in the UK by Dunlop and first appeared in 1953. In 1955, with powered inboard front disc brakes the first European production cars featured modern disc brakes. The first production car to feature disc brakes at all 4 corners was the Austin-Healey 100S in 1954. In 1965, Ford Thunderbird came with front disc brakes as standard equipment. Many early implementations for automobiles located the brakes on the inboard side of the driveshaft, near the differential, but most brakes today are located inside the road wheels.

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 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.

Ceramic disc brake were developed and tested by Porsche for their model Porsche 911 turbo in 1990. The results of the tests of ceramic disc brakes were found positive and soon Porsche commercialized this type of brake into major models. Soon after this Mercedes, Audi, Ferrari, Daewoo, Nissan and other major companies took forward the use of ceramic disc brake with advancements such as weight reduction, better composition, slotting, etc.

Historically, brake discs were manufactured throughout the world with a strong concentration in Europe, and America. Between 1989 and 2005, manufacturing of brake discs is migrating predominantly to China.
1.3 TYPES OF BRAKES

The brakes for automotive use may be classified according to the following consideration.

1. According to Purpose
   a) Service or primary brakes.
   b) Parking or secondary brakes.

2. According to Construction
   a) Drum brakes
   b) Disc brakes

3. Method of Actuation
   a) Mechanical Brakes
   b) Hydraulic Brakes
   c) Electric Brakes
   d) Vacuum Brakes
   e) Air Brakes

4. Extra Braking Effort
   a) Servo Brakes or Power assisted brakes
   b) Power Operated Brake
2.1 CONSTRUCTIONAL FEATURES OF DISC BRAKE

Disc brakes offer better stopping performance than comparable drum brakes, including resistance to "brake fade" caused by the overheating of brake components, and are able to recover quickly from immersion (wet brakes are less effective). Unlike a drum brake, the disc brake has no self-servo effect and the braking force is always proportional to the pressure placed on the braking pedal or lever.

As shown in fig a disc brake consists of a cast iron disc bolted to the wheel hub and a stationary housing called caliper. The caliper is connected to some stationary part of the vehicle, like the axle casing or the stub axle and is cast in two parts, each part containing a piston. In between each piston and disc there is a friction pad held in position by retaining pins, spring plates etc., passages are drilled in the caliper for the fluid to enter or leave each of the housing.
Two types brake discs are generally used the solid type and the ventilated type. But the ventilated type are thicker and heavier than solid type, they are liable to wrap at severe braking conditions, the dirt accumulates in the vents which affects cooling and apart produces wheel imbalance.

The discs of the brakes are made of pearlite gray cast iron. The material is cheap and has good anti-wear properties. Cast steel discs have also been employed in certain cases, which wear still less and provide higher coefficient of friction. Their main drawback is the non uniform frictional behavior.

On non-driving wheels, the centre of the brake disc or hub contains the wheel bearings. The hub can be part of the brake disc or a separate assembly between the wheel and hub with nuts or bolts. On driving wheels, the disc is mounted onto the driving axle and may be held in place by the wheel. On front wheel drive vehicles, it can be mounted on the front hub and wheel bearing assembly.
2.2 WORKING OF DISC BRAKES

When the brake pedal is depressed, a push rod transfers the force through a brake booster to a hydraulic master cylinder. The master cylinder converts the force into hydraulic pressure, which is then transmitted via connecting pipes and hoses to one or more pistons at each brake caliper. The pistons operate on friction pads to provide a clamping force on a rotating flat disc that is attached to the wheel hub. This clamping tries to stop the rotation of the disc, and the wheel.

Fig 2: Working stages of Disc Brake

Applying brakes can absorb a lot of vehicle energy so friction between braking surfaces generates great heat. Brake parts withstand very high temperatures. The design of the disc is hollowed out with fins joining together the disc's two contact surfaces. This "ventilated" disc design helps to dissipate the generated heat. Many brakes have many small holes drilled through them for the same purpose. Additionally, the holes aid the pads in wiping water from the braking surface. Other designs include "slots" - shallow channels machined into the disc to aid in removing used brake material from the brake pads. Slotted discs are generally not used on road cars because they quickly wear down
brake pads. However this removal of material is beneficial to race cars since it keeps the pads soft and avoids vitrification of their surfaces. Some discs are both drilled and slotted.

Most of the friction area of a disc is exposed to air so cooling is far more rapid than for a drum brake. Unlike with drum brakes, brake fade is rare. Because of their shape, discs tend to throw off water. So after being driven through water, they operate almost immediately.

### 2.3 MATERIALS USED FOR DISC BRAKES

The materials used for the manufacture of disc have evolved over the years. Different materials used for the manufacturing of discs are:-

1. Grey cast iron disc
2. Aluminium disc
3. Carbon-fiber disc
4. Ceramic disc.

Cast-iron disc is the heaviest of all types and also has a disadvantage in formation of rust. They usually range from 6-8 kgs for each disc of a car. But they are still preferred for high power vehicles.

Aluminium alloy discs are light, they were less resistant to heat and fade. Aluminium is better rotor material than cast iron due to two main reasons: its density is as one third as cast iron but its thermal conductivity is three times greater. These factors made it possible to construct a much lighter brake disc.

In contrast, carbon-fiber disc is most heat-resisting yet is by far the lightest, however, it requires very high working temperature, and otherwise braking power and response will be unacceptable.

Ceramics are inorganic, non-metallic materials that are processed and used at high temperatures. They are generally hard brittle materials that withstand compression very well but do not hold up well under tension compared to the metals. They are abrasive-resistant, heat resistant (refractory) and can sustain large compressive loads even at high temperatures. The nature of the chemical bond in the ceramics is generally ionic in character, and the anions play an important role in determination of the properties of the
material. Typical anions present are carbides, borides, nitrides and oxides. The different types of ceramics are clays, refractories, glasses etc.

3.1 MANUFACTURING OF CERAMIC BRAKE DISCS

In the earlier days, the brake discs were made from the conventional brittle ceramic materials would have disintegrated into a thousand pieces under slightest pressure. The research division of Daimler Chrysler has developed techniques to make carbon fiber reinforced brake discs which avoid the brittleness problem. In the earlier days, long carbon fibers were used. Later the use of short carbon fibers increased the efficiency.

The composites for producing fiber reinforced ceramic brake discs are short carbon fibers, carbon powder, and resin mix. The process involves first compressing the carbon fibers, carbon powder and the resin mix together and then sintering at 1000 degree Celsius. In the furnace a stable carbon frame work created. This consists of carbon fibers in a carbon matrix. Once cooled this material can be ground like wood and the brake disc obtains its final shape.

Together with silicon the ground break disk blank is then inserted into the furnace a second time. The pores in the carbon framework absorb the silicon melt like a sponge; the fibers themselves remain unaffected by this process. The ceramic material is created when the matrix carbon combines with liquid silicon. This fiber reinforced ceramic material cools over night and the gleaming dark grey brake disc is ready.

Resin is a binder, which holds the different constituents together. Resins are of two types:

1. Thermosetting resins
2. Thermoplastic resins

Thermoplastic resins are those, which can be softened on heating harden on cooling. Repeated heating and cooling does not affect their chemical nature of materials. These are formed by addition polymerization and have long chain molecular structure.
Thermosetting resins are those resins which, during molding process (by heating) get hardened and once they have solidified, they cannot be softened i.e. they are permanent setting resins. Such resins during moldings, acquire three dimensional cross linked structures with predominantly strong covalent bonds. They are formed by condensation polymerization and are stronger and harder than thermoplastic resins. They are hard, rigid, water resistant and scratch resistant.

3.2 COATING OF CERAMICS ON CONVENTIONAL BRAKEDISC

Earlier brake disc have been made of grey cast iron, but these are heavy which reduces acceleration, uses more fuel, etc. The new technology developed by Freno Ltd uses metal matrix composite for the disk, basically an alloy of aluminum for lightness and silicon carbide for strength. However it was found that, the ceramic additive made the disk highly abrasive and gave a low and unstable coefficient of friction. So it was realized that the surface had to be engineered in some way to overcome this problem. After experiments, Sulzer Metco Ltd found an answer in the form of a special ceramic coating. They developed thermal spray technology as well as manufacturing plasma surface engineering machinery used for the task and coating materials.
In use, the ceramic face requires a special carbon metallic friction pad, which deposits a layer of material on the brake disc. This coupling provides the required conditions of exceptional wear resistance, high and stable coefficient of friction.

The coated matrix composite discs were first used on high performance motor cycles, where the reduced gyroscopic effect had the additional advantage of making the cycles easier to turn.

Another company named Lanxide used aluminium as the disc material. To provide necessary abrasion resistance, aluminium discs have to be reinforced with a ceramic material, hence metal composite. They used silicon carbide also to increase the strength.

3.3 COMPARISON OF CERAMIC BRAKES AND CONVENTIONAL BRAKE DISC

Using a ceramic composite takes advantage of a material with outstanding hardness (and potentially long life) and an ability to retain its strength and shape at temperatures that would melt conventional iron brake material into a glowing puddle.

Simple single-ingredient ceramics tend to be brittle like dinnerware, though some types work well in turbochargers or as bearings for jet engines. To make ceramics that are tough enough for a brake disc, the material is manufactured as a composite: strands of carbon fiber, which are highly resistant to stretching, are embedded in the material.

Until now brake discs have been made up of grey cast iron, but these are heavy which reduces acceleration, uses more fuel and has a high gyroscopic effect.

Ceramic disc brake weigh less than carbon/carbon discs but have the same frictional values with more initial bite and cost a fraction of price. Carbon /carbon discs are used only in Formula 1 racing cars etc, because it is so expensive. More over ceramic
brake discs are good even in wet conditions which carbon / carbon disc notoriously fails to do.

But comparing their weight, you will see right away that we are looking at two different worlds, with ceramic brake discs more than 61 per cent lighter than conventional cast iron discs. In practice this reduces the weight of the car, depending on the size of the brake discs, by up to 20 kg. And apart from saving fuel, resulting in better and lower emission for the same mileage, this also means a reduction in unsprung masses with a further improvement of shock absorber response and behavior. Another is the manufacturer can add more safety features without adding to current weight.

3.4 CERAMIC DISC DAMAGE MODES
Discs are usually damaged in one of three ways:

- Warping
- Scarring
- Cracking

In addition, the useful life of the discs may be greatly reduced by excessive machining.

3.41 WARping

Warping is caused by excessive heat build up, which allows it to be disfigured. This can result in wheel shimmy during braking. The likelihood of warping can be reduced if the car is being driven down a long grade by several techniques. Use of a lower gear to obtain engine braking will reduce the brake loading. Also, operating the brakes intermittently - braking to a slower than cruising speed for a brief time then coasting will allow the brakes to cool between applications. The suitability of this is of course, dependent upon traffic conditions. Riding the brakes lightly will generate a great amount of heat with little braking effect and should be avoided. The wheel shimmy during braking is caused by thickness variation of the disc. Tests have shown that high temperature does not permanently warp discs.

3.42 ScARRING

Scarring can occur if brake pads are not changed promptly, all the friction material will wear away and the caliper will be pressed against the metal backing, reducing braking power and making scratches on the disc. If not excessive, this 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 safe thickness. For this reason it is prudent to periodically inspect the brake pads for wear (this is done simply on a vehicle lift when the tires are rotated without disassembly of the components). When practical they should be replaced before the pad is completely worn.

3.43 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. 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 rotor must be replaced.

3.5 ADVANTAGES AND DISADVANTAGES

3.51 ADVANTAGES

1. Ceramic brake discs are 50% lighter than metal brake discs. As a result, they can reduce the weight of car by up to 20kg. In case of a high speed ICE like train with 36 brake discs, these savings amount to 6 tons. And apart from saving fuel, this also means a reduction in unsprung masses with a further improvement of shock absorber response and behavior.

2. The ceramic brake disc ensures very high and, in particular, consistent frictional values throughout the entire deceleration process. With Porsche ceramic brake discs, a car was able to decelerate from 100Km to 0Km in less than 3 seconds. In the case of Daewoo’s Nexia, it takes about 4 seconds to stop the vehicle.
3. Brake temperature – a factor crucial to stopping distances with metal brake discs – is now only a minor factor, both the brake lining and ceramic brake disc retaining their high level of friction regardless of whether they are hot or cold. This not only shortens stopping distances by a couple of – often decisive – meters, but also spares the driver unpleasant surprises whenever having to apply the brakes, say, from a high speed.

4. Ceramics retain their resistance up to 2000 degree Celsius. Only if the temperature is excess of this, they lose their dimensional stability.

5. Initial field studies have shown that ceramic brake discs can still reliably bring an automobile to standstill even after 300,000 kilometers. Brake disc changes will in future be unnecessary.

6. They are not subject to wear, are maintenance free and are heat and rust resistant.

7. Heavily commercial vehicles can be braked safely over long distances without having to undergo brake maintenance. This dispenses with the need for expensive maintenance.

8. Ceramic brake discs do not rust under high oxygen concentration.

9. Dry and wet performances are excellent. Ceramics are water proof materials and the brake pads always remain dry.

3.52 DISADVANTAGES

The main disadvantage of ceramic brake discs is their high initial cost. Initially the ceramic matrix composite brake discs will be more expensive than the current technology metal ones due to the low manufacturing volumes and high cost of production. But, because of the advantages listed above, the ceramic brakes will work out to be cheaper in the long run.

3.6 APPLICATION

It was first introduced in Formula One, but applying to road cars seems impractical (F1 cars have warm up lap to bring the discs into appropriate working temperature), although the short-lived French sports car specialists Venturi made history by applying it to its road cars in the mid-90s.
The new 911 GT2 comes with the most effective braking system ever featured on a production Porsche: the Porsche Ceramic Composite Brake (PCCB) - a powerful new technology designed to cope with even the most extreme conditions on racetrack and road?

Mercedes-Benz’s the futuristic Vision GST concept car features 22 inch wheels, 'butterfly' doors, three-dimensional instruments, a 360 horsepower 5.5 litre V8 engine, and carbon-fiber reinforced ceramic disc brakes. Mercedes Benz SLR IS ALSO available with ceramic disc brakes.

3.7 CONCLUSION

Ceramic brake discs due to their advantages over the conventional brake discs are going to be the brake discs for cars in future. The special composition in the ceramic brake discs had turned the conventional brake disc into a material most suited for making brake discs. With the success of this in Porsche turbo car, many other racing cars and commercial vehicles are going to implement the ceramic disc in their cars.
REFERENCES

1. AUTOMOTIVE MECHANICS – CROUSE / ANGLIN
3. Automotive Engineering International Online Global Viewpoints, Nov_ 1999