

Applications – Chassis & Suspension – Brake system

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5 Brake system

5.1 Introduction

Automotive brake systems have been refined for over 100 years and have become extremely dependable and efficient. The brake system constitutes an integral part of an automobile. It allows the driver to slow or stop the vehicle and prevents a stationary vehicle from moving. Failure of the automobile brake system can lead to accidents, property damage, physical injuries or even death of an individual.

In recent years, brake systems have undergone tremendous changes in terms of performance, technology, design and safety. Today, anti-lock braking systems (ABS) are more or less standard. Modern ABS versions not only prevent wheel lock under braking, but also electronically control the front-to-rear brake bias. This function, depending on its specific capabilities and implementation, is known as electronic brake force distribution (EBD), traction control, emergency brake assist or electronic stability control system. A further technological step change can be expected with the emergence of the brake-by-wire technology.

Originally, most brake systems used mechanically actuated drum brakes with internally expanding shoes; i.e. the foot pressure exerted on the brake pedal was carried directly to semicircular brake shoes by a system of flexible cables. The mechanical brakes, however, were difficult to keep adjusted so that equal braking force was applied at each wheel. Furthermore, as vehicle weights and speeds increased, more and more effort on the brake pedal was demanded of the driver.

Consequently, mechanical brakes were replaced by hydraulic brake systems. The hydraulic brake system used in the automobile is a multiple piston system. The brake pedal is connected to a plunger in the master cylinder, which forces hydraulic oil through a series of tubes and hoses to the braking unit at each wheel. In a disk brake, the brake fluid from the master cylinder is forced into a calliper where it presses against a piston. The piston squeezes two brake pads against the brake disk, which is attached to the wheel, forcing it to slow down or stop. With drum brakes, the brake fluid is forced into the wheel cylinder, which pushes the brake shoes (or pads) outwards so that the friction linings are pressed against the drum. In either case, the friction surfaces of the brake pads convert the kinetic energy of the vehicle into heat.

For increased safety, modern car brake systems are broken into two circuits, i.e. a typical master cylinder includes actually two completely separate master cylinders in a single housing, each servicing two wheels. In order to better control the braking process, additional valves are necessary. Many cars are equipped with drum brakes on the rear wheels and disc brakes on the front. Drum brakes have more parts than disc brakes and are harder to service, but they are less expensive to manufacture, and they easily incorporate an emergency brake mechanism. Normally the disc brakes would engage before the drum brakes when the brake pedal is actuated. The metering valve compensates this effect and ensures that the drum brakes engage just before the disc brakes. Furthermore, regardless of brake type, the rear brakes require less force than the front brakes. For this reason, a proportioning valve reduces the pressure to the rear brakes. Modern cars use the anti-lock brake (ABS) hardware and the onboard computer to replace these proportioning valve systems with an electronic brake force distribution system in order to distribute the exact amount of pressure at each wheel to ensure a balanced braking operation.

Furthermore, a vacuum booster (or servo unit) is used in most hydraulic brake systems to provide assistance to the driver by decreasing the necessary braking effort. The vacuum booster is attached between the master cylinder and the brake pedal and multiplies the braking force applied by the driver. In gasoline engines, the manifold vacuum is used,

whereas in diesel engines (and vehicles with an electric powertrain), a separate vacuum pump is necessary.

A new development is the introduction of regenerative braking technologies. Regenerative braking is used on all hybrid and electric vehicles to recoup some of the energy lost during stopping. This energy is saved in the storage battery and used later to power the motor whenever the car is in the electric mode. While hybrid and electric vehicles automobiles still use conventional brakes at highway speeds, the electric motor helps the car brake at lower speeds, i.e. during stop-and-go driving. As the driver applies the brakes through a conventional pedal, the electric motor reverses direction and becomes an electric generator. The torque created by this reversal counteracts the forward momentum and eventually stops the car.

A similar approach can also be used in cars with internal combustion engines. In conventional systems, the generator (also known as the alternator) - which converts the engine's power output into electricity and charges the battery - is permanently driven by a belt connected to the engine. In BMW's Brake Energy Regeneration system, the generator is activated only when the foot is taken from the accelerator or the the brake is applied. The kinetic energy that would otherwise be wasted is now converted into electricity by the generator and stored in the battery. The result is a fuel saving of up to 3%.

5.2 Aluminium in the braking system

The typical brake system consists of disk brakes in front and either disk or drum brakes in the rear connected by a system of tubes and hoses that link the brake at each wheel to the master cylinder. Other systems that are connected with the brake system include the parking brake, electronic control systems like the ABS or the EPD system, etc. The major components of a vehicle's brake system are callipers, rotors, drum brakes, master cylinder and hydraulic boost units, electronic systems controlling the operation of the brakes, brake pedal, park brake lever/pedal, cables, pipes, hoses, sensors.



The brake system includes a wide range of components

Source: Bosch

For years, the brake system has included several aluminium components, in particular within the hydraulic system, e.g. the brake booster, valves, distributors, ABS system components, and brake pistons. The main reason for using aluminium for these components is its corrosion resistance, i.e. the prevention of clogging of the sensitive hydraulic system with corrosion products. The other important reason is the lightweighting potential of aluminium which is specifically important for those components of the brake system which are connected to the wheel, i.e. the unsprung masses. Aluminium has been used in various forms, such as sheet stampings, extruded sections and impact extruded parts as well as forgings and castings, depending on the type of component and the preferences of the car manufacturer. Examples of these brake system components will be shown under "3.3. **Components of the braking system**", demonstrating the versatility of the aluminium materials technologies.

Most of these aluminium applications will stay and probably even grow in future. The need for lightweighting remains, there is a clear trend for increased driver assistance by the introduction of electronic control units and new developments such as regenerative braking further increase the number of components in the braking system. On the other hand, the eventual introduction of the brake-by-wire technology will eliminate the need for some of these components.

A potential area for new aluminium applications are brake disks and drums. Disk and drum brakes work on the same principle: A pad (or shoe) presses against a spinning surface and converts the kinetic energy to heat. In general, automotive brake disks and drums are today made of cast iron or steel. Except for its relatively low wear resistance, aluminium would be a preferred material for these applications. Aluminium alloys are relatively strong and offer excellent fracture toughness. Aluminium disks and drums are also lighter than iron drums, which would lead to a significant weight reduction which is even more interesting since it affects the unsprung mass and the rotary mass of the vehicle. Furthermore, aluminium conducts heat much better which improves heat dissipation and reduces fade. The improved heat conduction will also prevent extreme heat accumulation on the disc or drum surface, where it can seriously damage the pads or prevent the brakes from working correctly.

In some cases, aluminium brake drums have been used, in particular for front-wheel applications. In order to avoid preliminary failure because of excessive wear, aluminium brake drums have an iron or steel liner on the inner surface of the drum, bonded or riveted to the aluminium outer shell. A similar approach could be used for disk brakes, where the friction ring could be created out of aluminium composite casting which embodies tough and hard materials. Newer developments include the use of particle-reinforced aluminium matrix composite materials, which - due to their special property characteristics - are eminently promising for applications in brake discs and drums. These developments are described in detail under "3.4. **Discs and drums**". But for the moment, this technology has not yet achieved any noticeable market penetration.

One reason is the existence of different competing technologies for high performance braking. Recently, carbon-ceramic and carbon-carbon composite brakes have been introduced in racing and sport cars. Carbon-carbon brake discs are composed of carbon fibres within a carbon matrix. However, moisture can reduce the braking power of carbon-carbon brakes. Additionally, carbon-carbon pads do not fully perform until they reach temperatures of about 300 °C. But above 500 °C, the carbon will react with the air and burn. Even at normal braking temperatures, some burning of the outer layers may occur and must be minimized by coating the rotor. Carbon-ceramic brake discs are composed of carbon fibres within a silicon carbide matrix (C/SiC). Carbon ceramic brake rotors are lightweight and can withstand over 1600 °C. On the other hand, they are very expensive and require special pads, delegating them for use mostly on high end applications.

5.3 Components of the braking system

As stated above, aluminium components are often found in the hydraulic system. These components have to satisfy highest safety requirements. Therefore in general, only wrought aluminium alloys and the respective product forms are used, for example forged or impact extruded parts. Often, components are also machined from extruded profiles with properly designed cross sections.



Extruded AlSi1MgMn profile specifically designed for the production of ABS housings

Source: OTTO FUCHS



Bosch ABS 8 – exploded view

Source: Bosch

However, also high quality casting techniques can be applied, e.g. for the production of master cylinders.



Cast aluminium master cylinders

Source: TRW Automotive



Co-operative regenerative braking systems for hybrid and electric vehicles

Source: Bosch

Aluminium components in the actual braking units at the wheels reduce the unsprung mass, but due to their corrosion resistance also ensure problem-free long term operation.



Drum brake with integrated parking brake function

Source: Bosch

In case of the disk brake, the brake calliper – the assembly which houses the brake pads and pistons - is the most important aluminium application. Most common calliper designs use a single hydraulically actuated piston within a cylinder, although high performance brakes use as many as twelve.



Brake calliper with an integrated mechanism for a parking brake function

Source: Bosch



Electric Park Brake which functions as a hydraulic brake for standard applications and an electric brake for parking (the traditional parking brake pedal or lever is replaced by a compact actuator switch)

Source: TRW Automotive

Additional aluminium application potential can be found in the brake lines. The brake fluid travels from the master cylinder to the wheels through a series of hydraulic tubes and reinforced rubber hoses. The rubber hoses are used only in places that require flexibility, such as at the front wheels, which move up and down as well as steer.



HYCOT™/® aluminium PA 12 coated precision drawn tubes ensuring excellent corrosion and stone impact resistance

Source: Hydro Aluminium Precision Tubing

5.4 Disc and drums

The use of aluminium as the basic material for brake rotors or drums presents a big challenge, but also a large potential for vehicle weight reduction. The resulting weight reduction is in this case even more interesting since it affects the unsprung mass and the rotary mass of the vehicle.

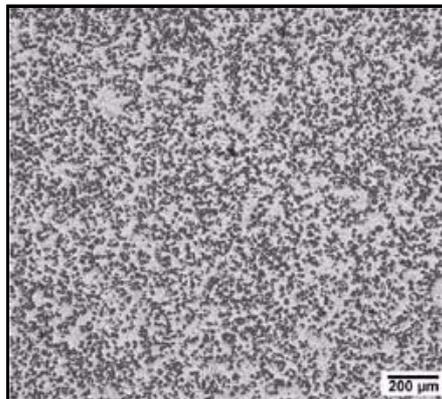
In the past, test applications of standard aluminium materials have revealed the shortcomings of lightweight aluminium rotors/drums in term of insufficient strength, thermal and wear resistance. The development of aluminium metal matrix composites (Al-MMC), however, resulted in a lightweight material with considerable improvements compared to standard aluminium in these areas. Brake rotor applications have focused on ceramic particulate reinforced aluminium alloy formulations because of their cost, availability, isotropy, and appropriate thermo-physical, mechanical, friction, and wear properties.



Aluminium Metal Matrix Composite brake discs and drums

Aluminium Metal Matrix Composite (Al-MMC) materials combine the light weight and strength of aluminium with the wear resistance and stiffness of ceramic reinforcements to create a durable, light weight alternative to Grey Cast Iron (GCI) for brake disks & drums. Compared to grey cast iron, Al-MMC materials offer distinct advantages, i.e.:

- ⤴ superior thermal properties
- ⤴ low noise susceptibility
- ⤴ high wear resistance
- ⤴ lower mass
- ⤴ excellent corrosion resistance.



Microstructure of an aluminium metal matrix composite with 20 vol.-% SiC

THE Aluminium Automotive MANUAL

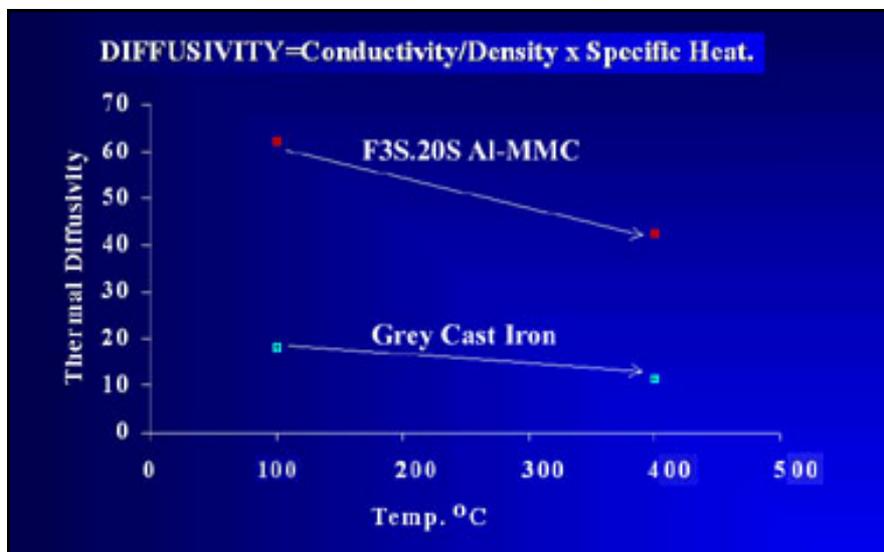
These specific material characteristics can be transformed to distinct product advantages:



More details can be found in the following diagrams:

1. Thermal diffusivity

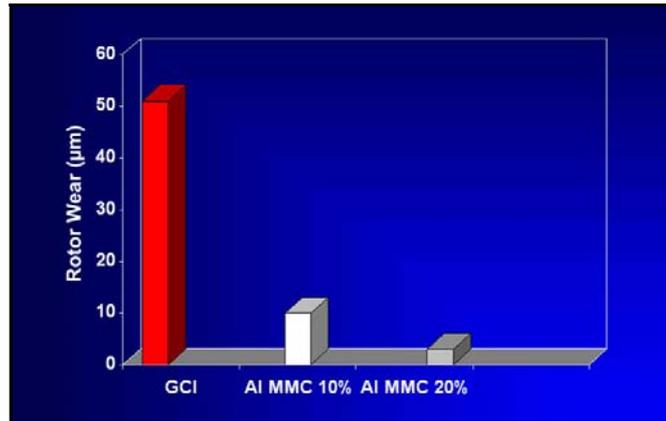
Thermal diffusivity is the ratio of the tendency of the material to conduct heat energy to the tendency to store heat energy, i.e. the most important thermal property for brake applications. The following diagram compares the thermal diffusivity of GCI with a 20 vol-% Al-SiC MMC over a relevant temperature range.



It demonstrates a larger difference in the balance of heat absorption and conduction between the two materials than the ratio of thermal conductivity alone would suggest.

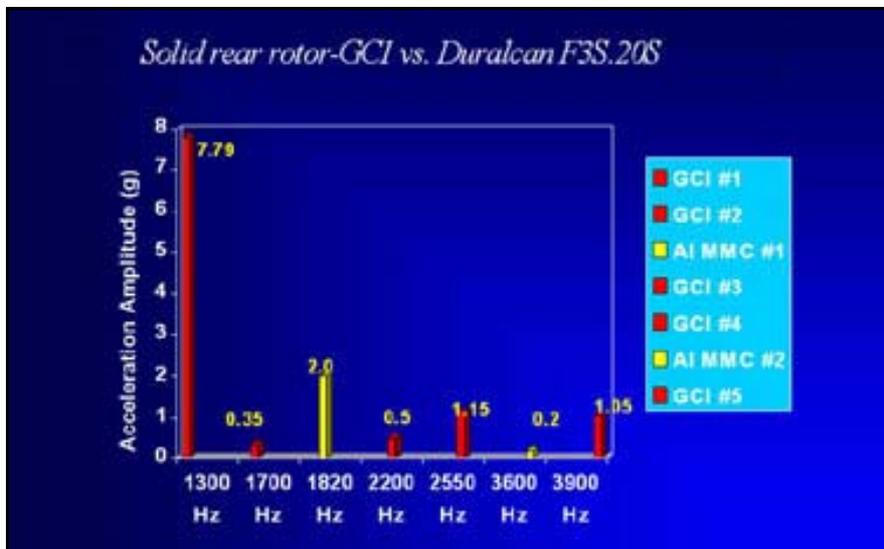
2. Wear resistance

The excellent wear resistance of Al-MMC reduces the roughness generation and thus leads to a reduction in rotor thickness variation. Therefore the introduction of Al-MMC might offer the possibility of a lifetime rotor or drum.

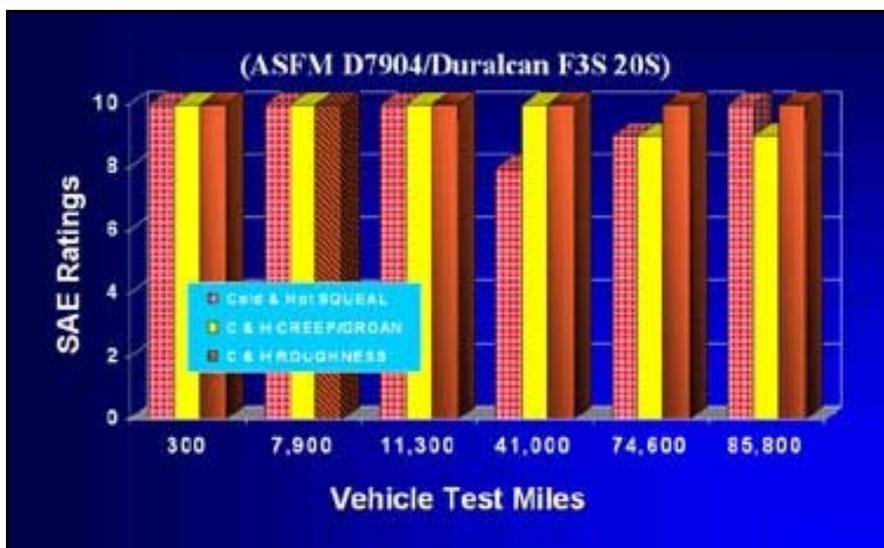


3. Noise generation

A comparison of the modal density shows that AI-MMC's have a lower propensity for noise generation than grey cast iron.



This corresponds to an advantageous NVH rating (SAE). The figure below shows typical rear NVH ratings for AI-MMC brake discs as a function of vehicle test miles:



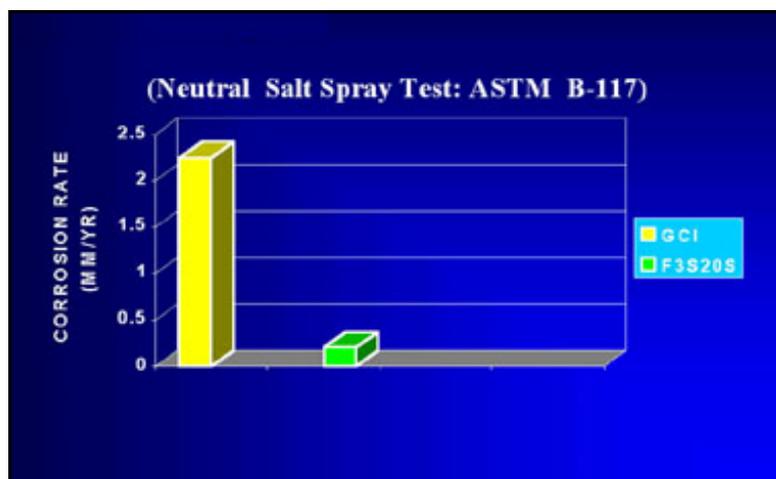
The following factors contribute to the lower noise of Al-MMC brakes:

- ⤴ lower running temperatures
- ⤴ stick / slip friction ratio closer to unity
- ⤴ lower modal density
- ⤴ lower specific gravity
- ⤴ lower acceleration levels
- ⤴ higher frequencies.

4. Durability and corrosion resistance

Compared to GCI, Al-MMC shows the following benefits:

- ⤴ maintains cooling capacity
- ⤴ maintains structural integrity
- ⤴ avoids damage to the braking surface
- ⤴ eliminates cosmetic issues
- ⤴ eliminates corrosion related judder.



On the other hand, Al-MMC brake discs and drums also require the consideration of specific design recommendations and manufacturing techniques. A big problem is in particular the machinability of these materials.