Technical Brake Pad Guide

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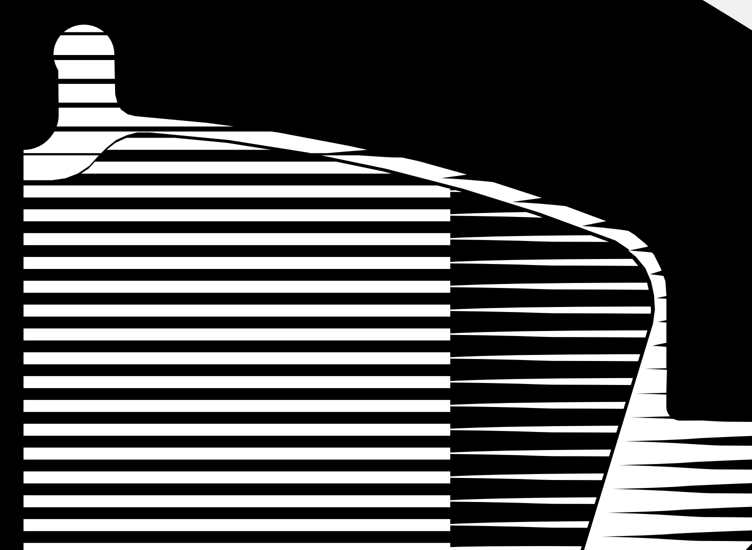

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Technical Brake Pad Guide

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PROLOGUE

The TECHNICAL BRAKE PAD GUIDE is intended to bring you closer to the world of friction, and specifically to take an in-depth look at concepts relating to the development of friction materials, which many professionals in the automotive sector are unaware of.

The brake system, and specifically the brake pads, would initially appear to be a set of very simple elements. As they do not have any complex mechanisms, the general underlying perception of them in garages is that they are straightforward elements. However, as will be seen throughout this guide, they are in fact very complex. Their installation may not perhaps involve any major difficulties, but we should at least take into account the appropriate assembly criteria. The result of this perception is that brake pads are not considered to be a critical element within the context of the complexity of modern vehicle components.

The aim of this guide is to ensure that friction materials, and brake pads in particular, are afforded the necessary level of importance given that, as will be seen in the chapters of this book, they are "live" elements. This means that their frictional characteristics will vary during their lifetime according to the conditions to which they are subjected, as they are affected by variables as disparate as speed, circuit pressure, the system design, working temperature, etc.

There are very few publications which discuss friction materials from the point of view of garages, in which the main problems which usually happen are identified and the solutions necessary to correct them are provided.

REMSA therefore aims to provide a more in-depth view of the importance of using the highest quality friction materials in order to prevent, as far as possible, all the problems caused by the use of pads of dubious quality in garages.

The brake rotor has also been discussed to a certain extent, as due to it being a component with a very simple appearance, it can also cause problems in braking, sometimes attributed to the brake system or pad and not to the rotor itself.

In summary, this guide has been written for repair professionals with a certain level of theoretical knowledge of brakes who are looking to increase their "know how". You will be the judge of whether or not we have been successful.

REMSA
Technical Department

CHAPTER 1

ANALYSIS OF THE FORCES GENERATED IN BRAKING

1. INTRODUCTION

One of the fundamental systems of any vehicle is that which enables it to reduce its speed and even stop when required by the vehicle driver.

VOCABULARY:
“Brake: slowing or stopping the movement of a machine or carriage with the brake.”

The requirements of a vehicle’s brake system are as follows:

- Capacity for braking of the system to stop the vehicle at all times.
- Slowing or stopping the vehicle in safe conditions.
- Slowing or stopping the vehicle in the shortest possible distance.
- Slowing or stopping the vehicle in all allowable vehicle load conditions.
- Slowing or stopping the vehicle in all road surface conditions.
- Slowing or stopping the vehicle in all environmental conditions.
- The braking process of the vehicle must be gradual.
- The braking process must not require a large effort by the vehicle driver.

The brake system is one of the most important active safety systems for all types of vehicles. This guide will focus on the brake systems for cars.

The operating principle of a braking system is the reduction of kinetic energy and/or potential in order to convert it into heat energy. All the energy possessed by the vehicle at any particular time must be converted during the braking process until the vehicle has come to a complete stop, if necessary. The conversion of the vehicle’s energy is carried out during the braking process by means of devices known as brakes.

This conversion of energy achieves a reduction in the speed of the vehicle, but the energy which has been turned into heat energy must be quickly dissipated by the brake system; they must therefore be of an adequate size to achieve this.

The fundamental concepts relating to vehicle braking will be analysed in this chapter, particularly those concerning the optimum braking distribution and the deceleration process.

The load distribution on the axles of a modern vehicle when stationary is approximately 60% of the total weight on the front axle and 40% on the rear axle. Clearly this **static** load distribution is modified in **dynamic** conditions according to the acceleration or deceleration to which the vehicle is subjected.

As an initial hypothesis, the vehicles will be considered as rigid bodies, which are not therefore equipped with a suspension system. It will also be considered that the movement of the vehicle will be in a straight line, without taking lateral forces into accounts. The analysis of the stresses and movements associated with the braking process will therefore be made on the basis of the diagram of the two-dimensional free body shown in the diagram below.

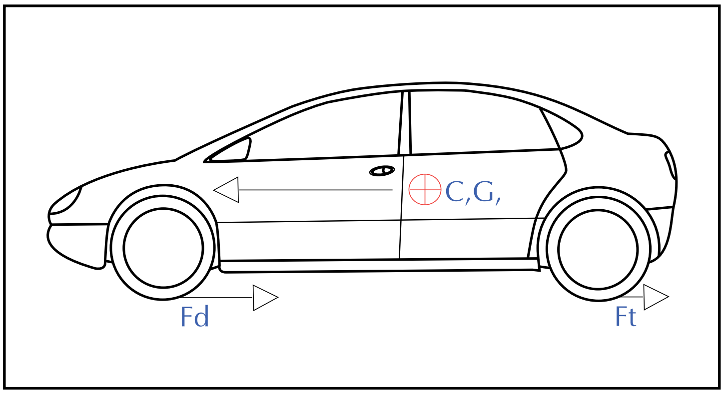


Diagram of the forces in play during the braking process

The main forces in play during the braking process of the vehicle are represented as follows:

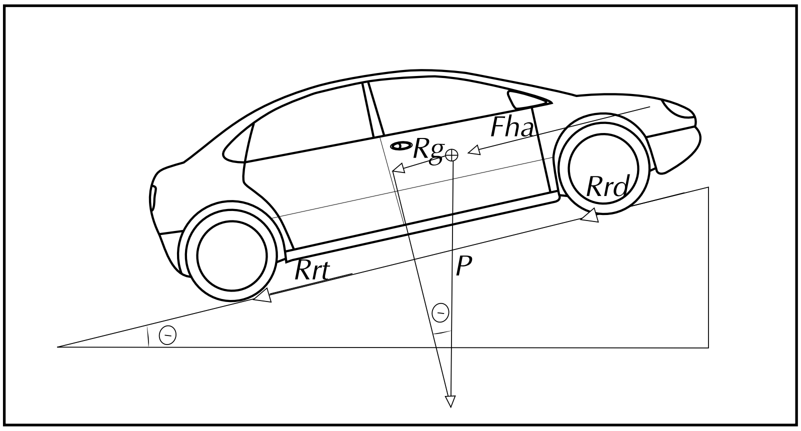
As can be seen in the diagram, the inertia of the vehicle when braking generates a force (F_i), which acts on the centre of gravity of the vehicle and which normally, as this point is situated at a greater height than the wheel axle, generates pitch torque in the vehicle which modifies the load distribution on the axles. Although this dynamic load distribution during braking depends on other factors such as the static load distribution, the height of the centre of gravity and other factors, it can be estimated that in a **typical** vehicle this distribution is 75% on the front axle and 25% on the rear axle.

This situation means that the front and rear brakes, as well as the characteristics of the friction material of the brake pads or shoes, must have different dimensions and/or coefficients in order to prevent the rear wheels from locking up.

If the rear wheels lock up, the directional stability of the vehicle would be hugely compromised and in such a situation the car would tend to turn on its axis, as will be seen in more detail later.

2. FORCES AND MOMENTS ACTING IN THE BRAKING PROCESS

Shown below are the different stresses which intervene during the braking process. Although some of them may seem irrelevant, we will see that they are vitally important depending on the type of driving carried out.



BRAKING FORCE

The main retarding forces of the vehicle in the braking process are those developed on the surface of the wheels as a consequence of their contact with the road, resulting from the application of braking moments which are opposed to their movement. In other words, the braking forces.

The maximum braking force and maximum traction force have limits which coincide in both cases with that imposed by the “tyre/ground” contact. The maximum braking force will also depend on the brake system of the vehicle, as will the maximum traction force, as it will also depend on the limit imposed by the power of the vehicle’s engine.

The critical limit is that imposed by the existing grip between the tyre and the ground. When this limit is exceeded, in the specific case of the brake system, the wheels will lock up, either those for the front or rear wheel assembly of the vehicle, causing the vehicle to skid on the road surface; an unwanted effect, as will be explained below.

ROLLING RESISTANCE

The rolling resistance and aerodynamic resistance of the vehicle intervene as retarding forces in the braking process. Although their influence is small compared to the braking forces, they do participate in the braking process of the vehicle, albeit to a lesser extent. The rolling resistance, fundamentally generated by the tyre/ground friction and mechanical losses in the transmission system, is generally small in comparison with the other forces in play, the magnitude of which will increase virtually in proportion to the speed.

AERODYNAMIC FORCES

The forward aerodynamic forces are only of interest as retarding forces at high speeds. At moderate or low speeds they can be discounted when compared with the value of the braking force.

The aerodynamic forces are important at high speeds as their value increases with the square of the speed of the vehicle. In other words, when we double the speed of a vehicle, for example from 80km/h to 160km/h, the forward aerodynamic force, for example 40kg, is multiplied by four, requiring a thrust of 160kg. The diagram below shows the increase in the aerodynamic and rolling forces, as well as the necessary power that the vehicle must have in order to overcome them.

Speed (km/h)	Aerodynamic Resistance (kg)	Rolling Resistance (kg)	Total Resistance (kg)	Power Necessary (HP)
40	5.3	10.0	15.3	2.3
80	21.6	14.0	35.6	10.7
120	48.6	19.0	67.6	30.6
160	86.4	26.0	112.4	67.9
200	135.0	32.0	167.0	126.2

This table has been produced using the dimensions of an average-size vehicle.

ENGINE AND TRANSMISSION RESISTANCE

The resistance offered by the engine is in many cases an important factor in the braking process. The power, as resistant torque, which the engine offers in braking processes during which it remains connected to the wheels through the transmission, is important when the engine turns at a high number of revolutions and decreases with speed, becoming small in the last interval of a braking process.

In prolonged decreases in speed, particularly in the case of heavy vehicles, the retention generated by the engine is of vital importance in order to keep the friction elements of the brakes from heating up and the consequent high levels of wear.

If the deceleration with which we wish to brake is sufficiently high, and the clutch is engaged, the demands on the brake system are much greater than if we disengage the clutch in order to brake.

Obviously, this braking effect is greater in diesel engines with compression ratios of approximately 20:1 than in petrol engines with compression values of 9:1.

3. CONDITIONS IMPOSED BY GRIP: OPTIMUM BRAKING FORCE DISTRIBUTION

Grip conditions in different tyre friction conditions:

μ = 0.9 … … … … … … … Dry tar
μ = 0.8 … … … … … … … Dry rough asphalt
μ = 0.6 … … … … … … … Cobbles
μ = 0.5 … … … … … … … Wet rough asphalt
μ = 0.4 … … … … … … … Wet used asphalt
μ = 0.3 … … … … … … … Wet cobbles
μ = 0.1 … … … … … … … Ice

The locking up of the wheels on one axle produces negative effects, as in a locking situation the friction coefficient between the tyre and the road (μ=0.75) acquires a value lower than that of maximum grip, causing the tyre to skid on the road. When the wheels lock up, the value of the braking force therefore decreases in comparison with the maximum potential force which can be obtained in rolling conditions prior to the locking up of the wheels, as the tyre/ground friction coefficient falls to very low values of approximately μ=0.2, or lower on wet surfaces.

The above effect, whilst of great interest, is not the most important. The locking up of the wheels means that the tyre/ground grip in the longitudinal direction is exceeded. The interaction between both elements will therefore be unable to provide resistance to counterbalance possible lateral forces, however small they may be. Since in practice it is impossible for a situation free of any lateral stresses to occur, the vehicle may undergo a lateral movement (due to wind, load distribution, etc.) the effect of which will be different according to the axle whose wheels have locked up.

If it is the wheels on the **front** axle that lock up, the inertia forces applied to the centre of gravity and the friction and grip forces on the wheels produce a yaw moment which decreases with the value of the lateral disruption. This causes the system to be stable; in other words, the forces tend to make the vehicle recover its longitudinal position. In this situation, a certain loss of directional control is caused which is less serious, in general terms, than the instability caused by the locking up of the rear axle and the vehicle initially tends to follow a straight path without responding to steering.

If it is the **rear** axle that locks up, the grip with the ground provided by the wheels on this axle will decrease dramatically as has been seen above; any instability may thus cause the vehicle to turn on its axis, leading to a complete loss of directional stability. In other words, if in a normal driving situation we apply the handbrake firmly until the tyres lock up, the vehicle will tend to skid from the rear end until facing the other way.

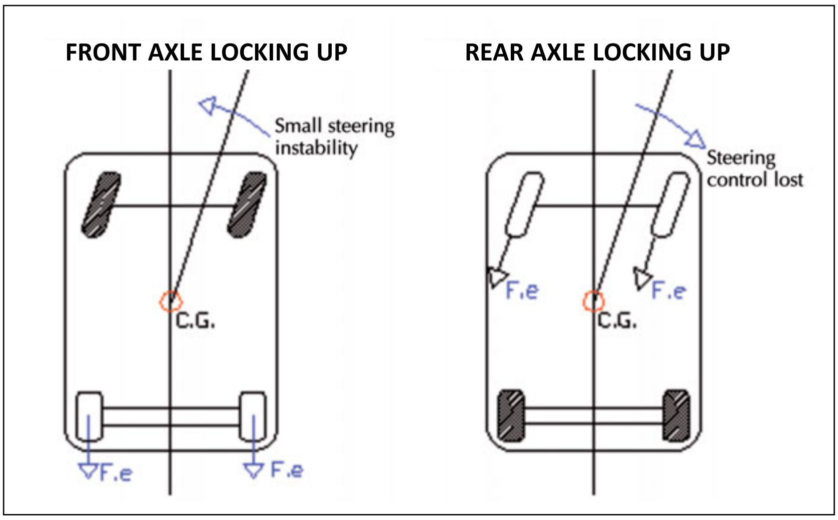


Diagram of the forces caused by the locking up of an axle

Some important conclusions can be drawn from the above:

1. The locking up of the wheels on the rear axle of a vehicle with two axles causes a great deal of irreversible directional instability.
2. The locking up of the wheels on the front axle of a vehicle with two axles can cause a loss of directional control.
3. From all of the above it can be concluded that action must be taken in both the design of the brake system and driving, in order to prevent the locking up of the front and rear wheels. Under sharp braking, particularly in low grip conditions, locking up may occur and it is unlikely that the wheels on both axles will lock at the same time. In this case, it is less unfavourable for the front wheels to lock up first. Elements that limit braking in the rear axle are therefore added to the system to ensure that it does not lock up before the front axle.
4. The locking up causes the normal grip coefficient (μ=0.7) to decrease, being passed on to the skid resistance value (μ=0.2) which, at best, if no serious alteration of the trajectory occurs, would cause the braking distance to increase in relation to optimum braking conditions; in other words, if maximum use were made of the grip.

It can thus be seen that making good use of the available grip in each axle is fundamental as it is a critical part of braking. Maximum use will be made of the grip if the stress transmitted by the brake system to each wheel is proportional to the dynamic load it bears. In order to optimise braking and prevent the locking up of the wheels, the optimum distribution of braking forces is studied.

In addition, some manufacturers specify that the friction material of the brake on the rear axle must have a friction coefficient (μ) lower than that of the front axle. Others accept friction materials with the same coefficient, but **never** allow the rear brake to have a higher friction coefficient than the front axle in any situation of circuit pressure, speed or temperature.

It is therefore highly advisable to replace the brake pads in both axles with pads produced by the same manufacturer, as fitting materials from different manufacturers may lead to problems such as those described above.

OPTIMUM BRAKING FORCE DISTRIBUTION

When the vehicle is stationary, the mass of the vehicle is distributed between the front axle and the rear axle, with values allowed for by the design of the vehicle. Almost all of today’s commercial vehicles are slightly heavier in the front area than in the rear as not only is the engine located in the front, but as the transmission, gearbox, differential, etc. operate on the front axle, their masses are also located on it.

The lower weight in the rear axle means that the force distribution design is fundamental if the **locking up** of the rear wheels is to be avoided. What’s more, as has already been mentioned, when the vehicle brake system is activated, there is a pitching moment around the centre of gravity which generates a load transfer from the rear axle to the front axle. This means that not only is the rear axle lighter than the front axle but, due to the vehicle dynamics, whenever the brake is activated the rear axle will also transfer part of the load to the front axle.

The value of the load transfer which takes place from the rear to the front axle when braking depends on the height of the vehicle’s centre of gravity and its wheelbase; in other words, the distance between axles.

Due to all these variables, the braking force which will be applied to the front axle is not equal to that of the rear axle. The same thing can be said about the forces which are applied during acceleration. The percentage of braking which must be generated in the front axle and that which must be generated in the rear axle will however be determined, using a tyre/ground friction coefficient with a value of μ=0.8. The distribution would be 0.75 % of braking in the front wheels and 0.25 % in the rear wheels (point O).

For a grip value between the tyre and the ground of μ =0.80, point O, the intersection of both curves, shows the optimum braking point and, therefore, the distribution of braking stresses described above. If a braking distribution is established in the vehicle with 86% of braking in the front axle and 14% in the rear axle (point B), the locking up would occur first in the front wheels, achieving maximum deceleration of 0.62, well below the optimum value. If on the other hand the braking distribution coefficient is established at 40% in the front wheels and 60% in the rear wheels (point A), the rear wheels would lock up first and the deceleration limit would also be established at a value

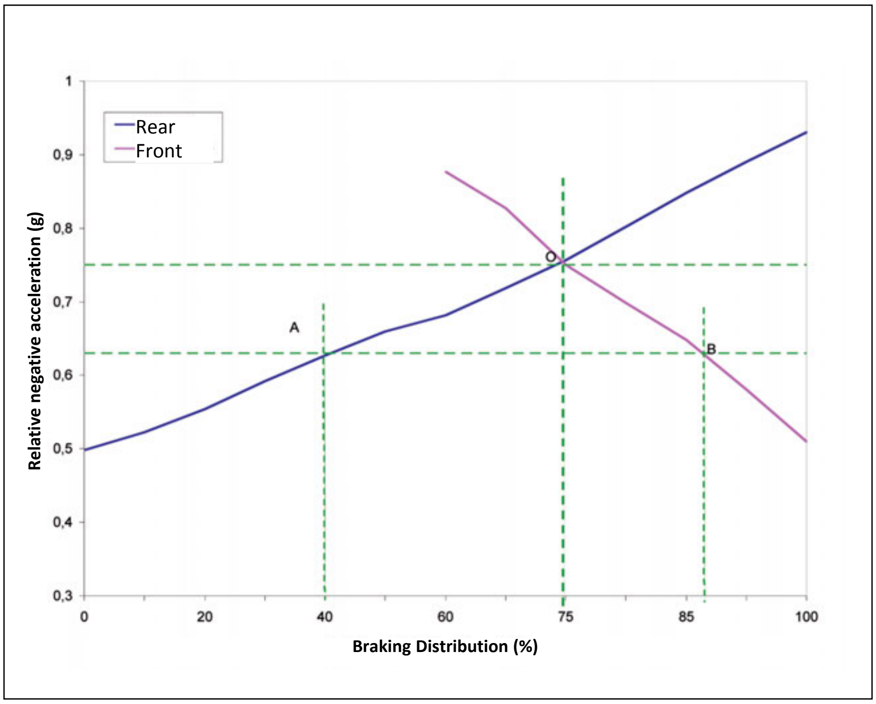


Diagram showing the optium braking distribution between both axles

of 0.62, well below the optimum value and also with the damage caused by the locking up of the rear axle, seen above. As can be seen, the best solution is that represented at point O, with a braking distribution of 75% in the front axle and 25% in the rear axle.

In order for these braking distribution values to be maintained with maximum grip, thereby achieving the greatest deceleration, most of vehicles are equipped with pressure regulators which vary the rear circuit pressure in order to prevent the locking up of the tyres and the negative consequences which have already been mentioned.

CHAPTER 2

INTRODUCTION TO TRIBOLOGY

1. WHAT IS TRIBOLOGY?

Tribology is a science and technique that studies the interaction between surfaces in relative motion and the problems related to them: wear, friction, adhesion and lubrication.

Various phenomena appear in the interaction between two surfaces, knowledge of which is of vital importance.

The three fundamental phenomena are as follows:

- FRICTION: an effect caused by the existence of tangential forces which appear between two solid surfaces in contact when these surfaces are joined together by the existence of normal forces.
- WEAR: consists of the disappearance of material from the surface of a body as a consequence of interaction with another body.
- ADHESION: the capacity to generate normal forces between two surfaces after they have been held together. In other words, the capacity for two bodies to be joined together by the prior generation of binding forces between them both.

The brake system is one of the most important active safety systems for all types of vehicles. This guide will focus on the brake systems for cars.

The aim of tribology is not only to minimise the disadvantages. Depending on the situation, there may be different objectives to be achieved:

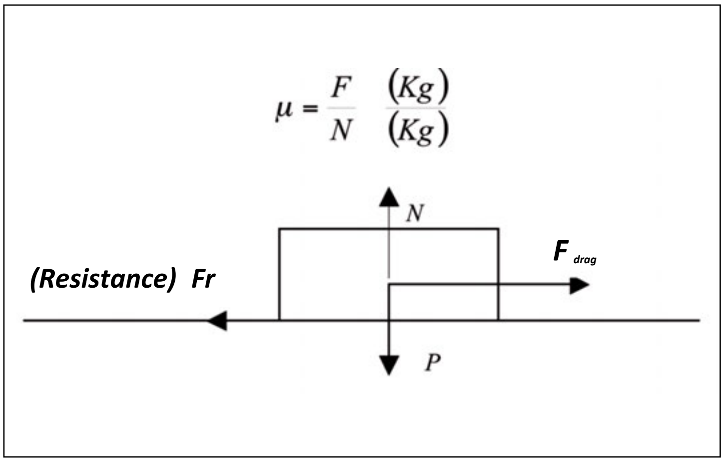
❏ Minimum wear and minimum friction: bearings, gear units, cams, etc. thanks to lubrication and coating layers.
❏ Minimum wear and maximum friction: brakes, clutches, tyres, etc. with wear-resistant materials.
❏ Maximum wear and minimum friction: graphites, deposit of solid lubricants through sliding.
❏ Maximum friction and maximum wear: erasers.

To get an idea of the importance of solutions to tribological problems, in cars, for example, in which there are more than 2000 tribological contacts, tribological improvements can mean an estimated energy saving of 18.6%. In the energy field, it is estimated that in the USA 11% of the total energy consumed in four big sectors; transport, turbines, power generators and industrial processes; could be saved by introducing tribological advances. From the financial point of view a report produced in Germany revealed that the losses resulting from friction and wear equate to an annual energy loss of around 3 billion Pesetas.

2. FRICTION

Friction is the resistance to movement that exists when a solid object moves tangentially with respect to the surface of another solid object with which it is in movement.

Friction is expressed in relative terms of force, as the coefficient between the friction force and the nominal load over the contact surfaces, and is usually represented by μ, which is a non-dimensional coefficient; in other words, it has no units as the two forces are measured in the same units.



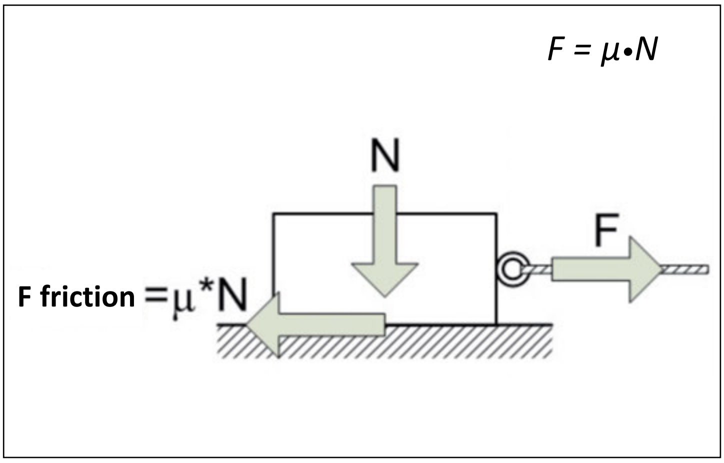
There are two situations to distinguish between:

1. STATIC FRICTION FORCE: that necessary to begin movement. If the tangential force applied is lower than this value, there will be no movement and the friction force will be equal to or greater than the tangential force applied.

2. KINETIC OR DYNAMIC FRICTION FORCE: that necessary to maintain movement. It has a lower value than the previous force.

The fundamental laws of friction are as follows:

- The friction force is proportional to the normal force.



- The friction force is independent of the apparent area of contact (Aa). Large and small objects from the same pair of materials therefore have the same friction coefficient.
- The friction force is theoretically independent of speed in this first approximation but is dependent on sliding, as it is in practice due to the sensitivity of friction materials to pressure, speed and temperature.

The typical friction coefficients of steel when it slides over other materials are shown in the table.

On a microscopic scale, the surfaces of solids have peaks and troughs, which we can evaluate by measuring the

MATERIAL 1 WITH MATERIAL 2		μ
Steel	Steel	0.62
Bronze	Steel	0.24
Graphite	Steel	0.10

surface roughness. Due to this roughness, when two surfaces come into contact they do not do so in all of the apparent area of contact (Aa), but contact will only be verified in some points of these rough areas.

The total area of the points in which contact is verified is called the real area of contact (Ar). This area is independent of the apparent area of contact.

These points of contact are those which withstand the normal load and generate the friction force.

As the normal load increases, the number of points of contact increases, and the real area of contact increases despite the fact that the apparent area remains unchanged.

The friction force is due to various effects involved in the provision of energy:

✓ Adhesion: the main component of friction.
✓ Deformation.
✓ Interaction between rough areas.

The existence of contaminant layers between the brake rotor and the friction material considerably reduces the friction forces.

The existence of a friction force causes the real area of contact to increase and also increases the scavenging of the intermediate layer (third layer), thereby increasing adhesion in comparison to simple contact.

It should be mentioned that when the sliding of one surface against another occurs at high speeds, the temperature increases due to the friction force between both materials opposing the movement so that a conversion of kinetic energy into heat (thermal energy) takes place with a subsequent increase in the temperature of both surfaces.

3. BRAKING

The braking of a moving body is one of the most complex areas of study of tribology.

When a vehicle brakes, what is achieved by means of the friction between two materials is the conversion of kinetic and/or potential energy (that carried by the object due to it moving or being at a certain height) into heat energy. What this conversion of energy produces is an increase in the overall temperature of the system as a whole.

The conversion of the energy happens in the contact between a fixed part attached to the stub of the vehicle (the caliper), and a movable part which turns at the same angular speed as the wheel (the rotor). When we press the brake pedal, the circuit is pressurised and the pistons of the calipers push the pads (fixed element) against the rotor (movable element).

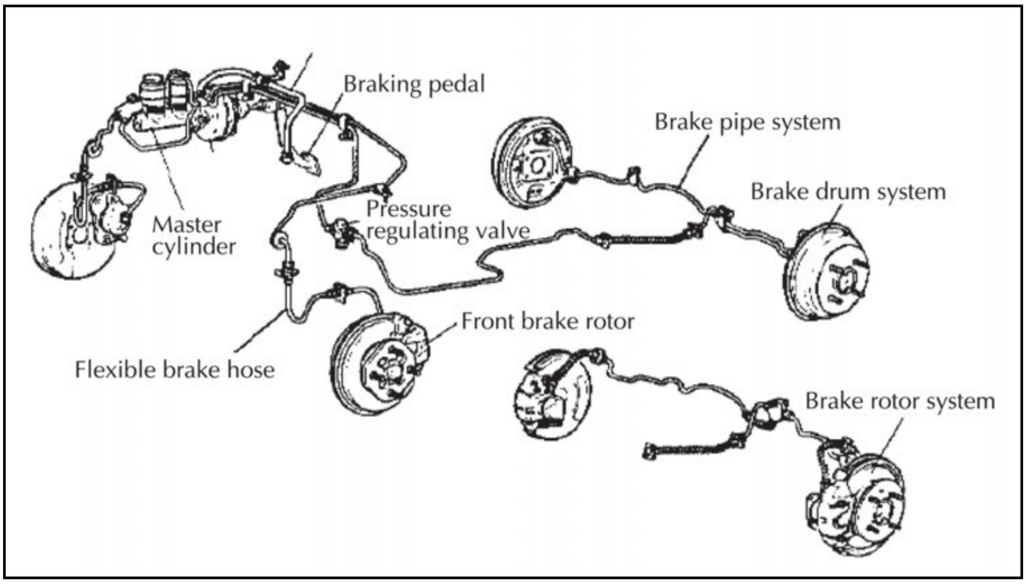
The contact between the pads and the rotor is where the conversion of the energy takes place; hence both elements have very distinctive characteristics, as they must be able to withstand high temperatures without wearing excessively but also have a good friction coefficient in order to slow down the vehicle.

The friction coefficient of the friction material must also be as stable as possible at different speeds and different pressures in the brake system so that drivers know what to expect when they need to decelerate their vehicle.

CHAPTER 3

THE BRAKING SYSTEM

The brake system of a modern vehicle is made up of the following elements:



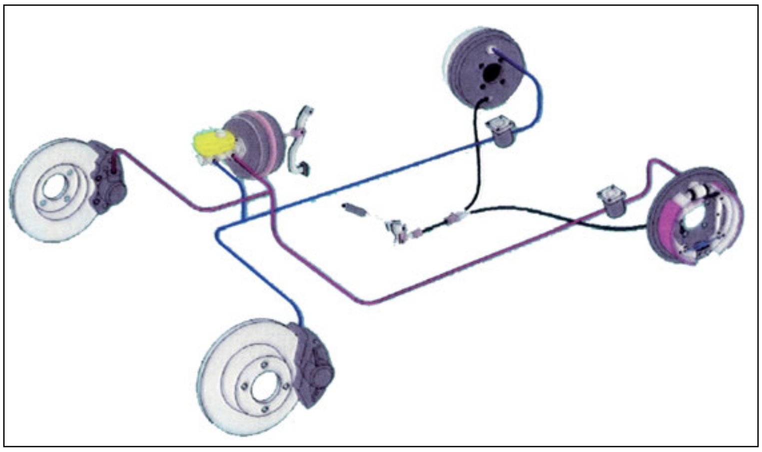


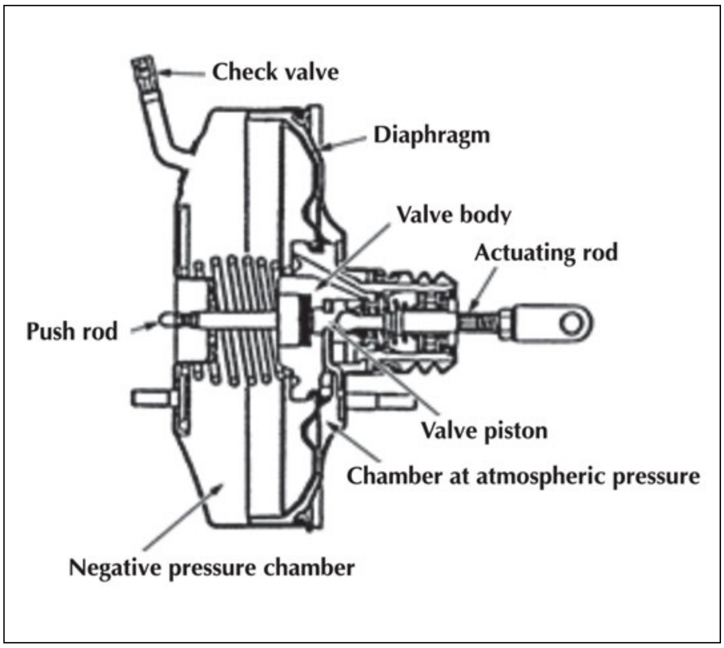
Diagram of a diagonal split brake system

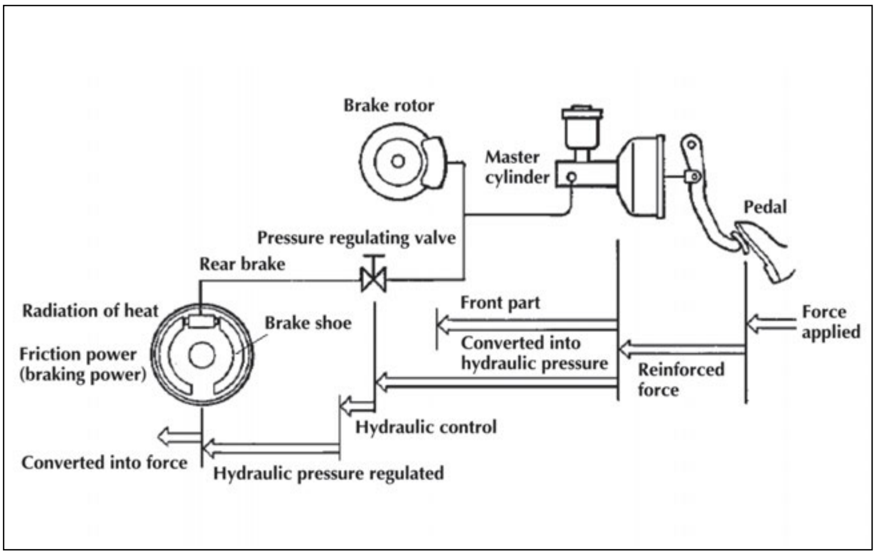
1. BRAKE BOOSTER:

The brake booster is a system which reduces the pressure that must be placed on the pedal in order to pressurise the circuit at the same pressure. In other words, it is an element which reduces the effort required from the driver to pressurise the circuit by pressing the pedal.

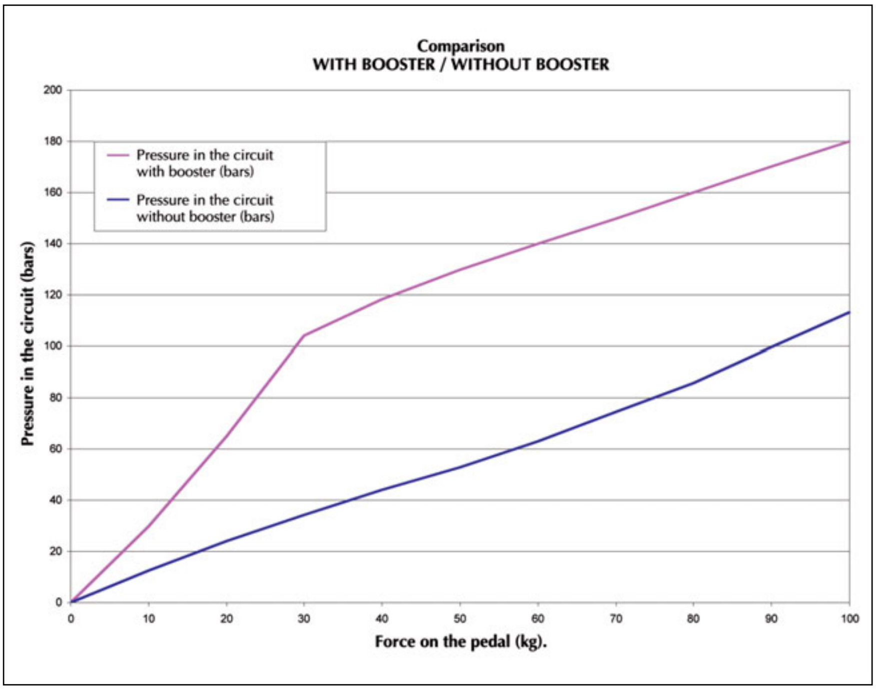
The advantage of the brake booster is not only that greater pressure can be applied to the hydraulic circuit and consequently to the caliper pistons, with less effort required by the foot, but improved brake proportioning is also achieved.

The most common brake boosters are currently those which act by means of a vacuum. These devices exploit the depression created in the intake manifold when the foot is taken off the accelerator to increase the force that the foot applies to the brake pedal.





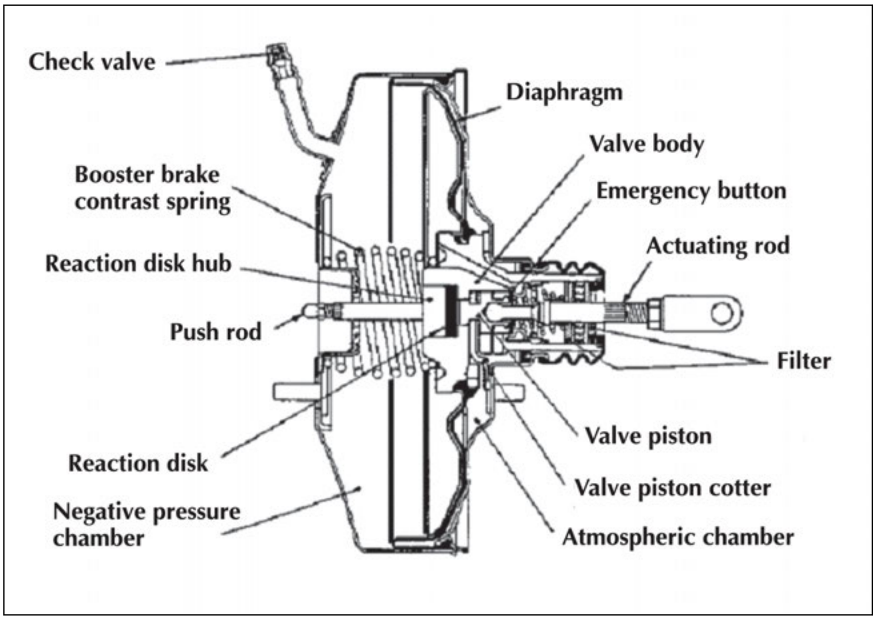
A brake booster is fitted between the brake pedal and the master cylinder which increases the force applied to the pedal with the help of a vacuum. Negative pressure is applied from the intake manifold to the master cylinder and atmospheric pressure is applied to the side of the brake pedal when it is pressed. In addition to the force applied to the brake pedal by the driver, the brake booster also applies the force produced by the vacuum in order to make the braking more efficient.



Comparison of the force of the pedal to be applied in a vehicle without brake booster and another equipped with brake booster

The typical pedal/booster effort values for the type of system shown above are as follows:

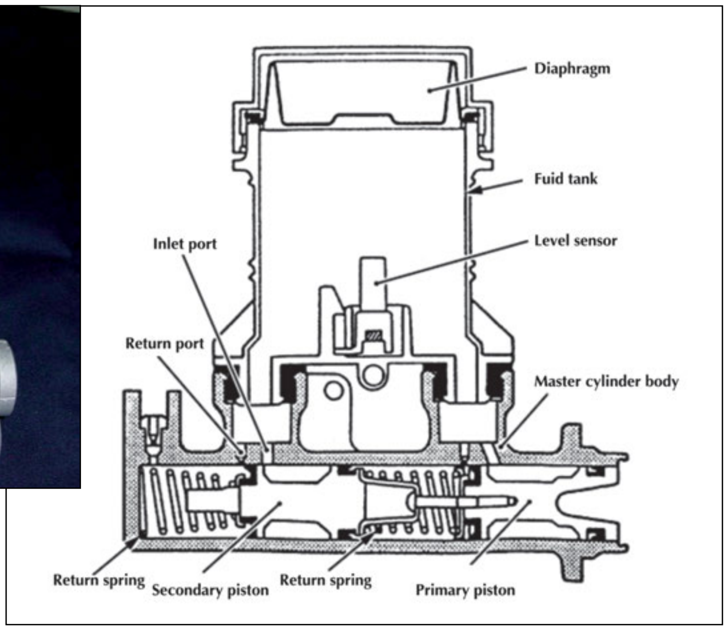
Force on the pedal (Kg)	**Pressure in the circuit with booster (bars)**	**Pressure in the circuit without booster (bars)**
0	0	0
10	30	13
20	65	24
30	104	34
40	118	44
50	130	53
60	140	63
70	150	75
80	160	86
90	170	100
100	180	113



2. MASTER CYLINDER

The master cylinder or main cylinder is responsible for pressurising the liquid throughout the hydraulic circuit. As current legislation requires vehicle manufacturers to ensure that these are equipped with dual circuit brakes, tandem brake pumps are used.

The tandem system means that the pump has two pistons, placed alongside each other, which are responsible for the supply of the fluid at the same pressure for each of the two independent circuits, normally distributed in an "X" shape. In other words, one circuit acts on the left front wheel and right rear wheel whilst the other acts on the right front wheel and left rear wheel, providing an element of safety in the event of problems of loss of efficiency in one of the two circuits.



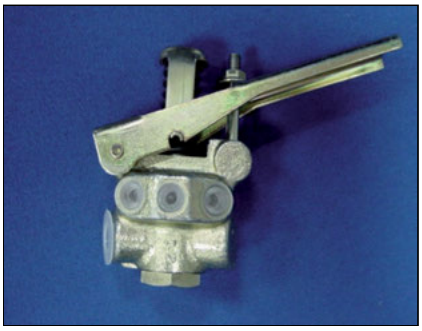
Brake pump with reservoir for brake fluid

3. BRAKE REGULATOR

The function of brake limiters or pressure regulators is to reduce the pressure that reaches the rear wheel assembly in order to ensure that these wheels do not lock.

The regulators have different operating methods:

- With a fixed cut-off point: when the pressure reaches a pre-established value it ceases to accept any more pressure.
- Gravity bases: depending on the load of the vehicle, the regulator provides more pressure in the circuit, as when the surface is lowered by means of a mechanical actuator the valve opens up. We should remember that the greater the weight withstood by the axle the greater the force necessary to slow it down.
- Depending on the deceleration of the vehicle.



Gravity-based brake regulator

4. BRAKE CALIPER

The brake caliper is the element responsible for supporting the pads in addition to pushing them against the rotor when the system is pressurised.

The caliper is a critical element of the brake system and is subjected to significant stresses during braking such as vibrations, water and other aggressive elements.

It is therefore very important for an inspection to be carried out, even if it is only a visual inspection if an ultraviolet camera is not available for the detection of cracks.

There are different types of brake calipers according to the brake system and the manufacturer. However, they are all based on the fact that after releasing the pressure of the circuit, they enable the brake pad to continue in contact with the brake rotor so that in the next braking process it will have an immediate effect without requiring any time to move towards the brake rotor. This contact is guaranteed by the caliper piston retainers and the hydraulic system itself and logically generates a permanent braking effect (residual torque) whose value is critical for the proper operation of the system.

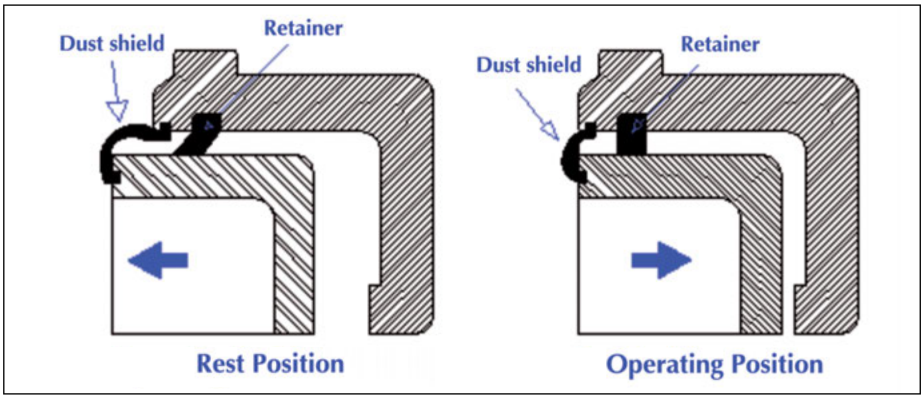
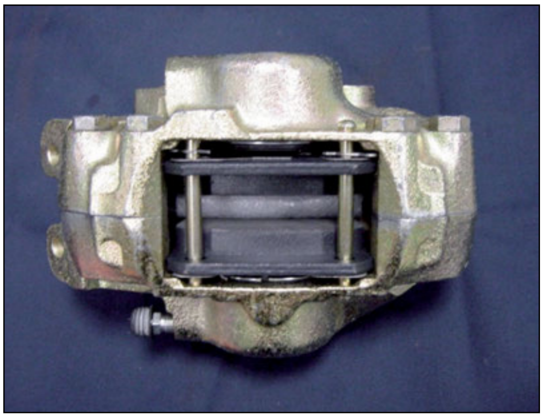


Diagram showing the operation of the caliper cylinder

High levels of braking torque (residual torque) can cause the system to heat up, leading to problems which are described later.

OPPOSED PISTON CALIPERS

The rotor brake with opposed piston calipers is attached to the mount flange by means of two bolts, and the calipers are assembled above the rotor which turns with the hub of the wheel. The cylinders on both sides of the fixed calipers are each equipped with a joint which is held in an angular slot in the cylinder housing. The cylinders and pistons are protected against dirt and water with an anti-dust cover. The sets of pads are fitted between the piston and the rotor in the slot in the calipers and are held in place with pins. The calipers for the rear wheels may have attachment holes incorporated for attaching a caliper-type handbrake activated mechanically which acts as a parking brake.



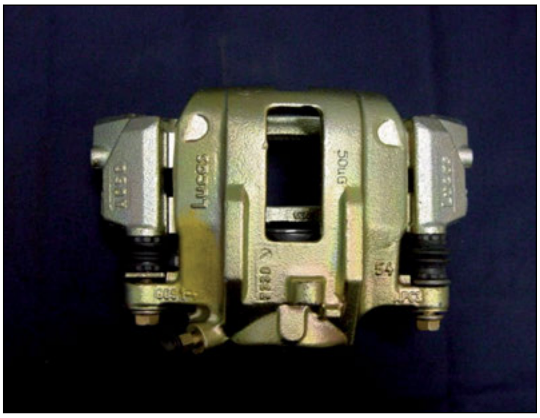
Double piston caliper

Its operating principle is simple: when the pedal is pressed down, the main cylinder pressurises the brake fluid, which pushes with equal force on each of the caliper pistons; these in turn push the pads against the rotor. The advantage of this system is that both pads are pushed with the same force against the rotor. The pedal effort applied is always directly related to the piston force (according to a ratio determined by the dimensions of the components), and therefore to the degree of braking. When the pedal is released, the existing hydraulic pressure in the brake system decreases, which means that the pistons return to their original position, helped by the joint between the pistons and the caliper body (also responsible for the unit being air tight). As the material of the pad wears, the pistons slide through the joint more when braking, so that the wear is automatically offset.

- **SLIDING CALIPERS:**

Rotor brakes with sliding calipers have been designed to recover the space lost due to the installation of McPherson suspensions, which have considerably restricted the available space as they change the drop angle of the wheels. This new type of caliper is replacing the double piston caliper with its improved advantages, including the following: the brake fluid is separated from the heat dissipation area, there is a large brake pad area and volume so that a greater friction surface is achieved for braking and being wider they have a longer useful life, lower weight, constant force in both pads and reduced residual torque due to the controlled retraction of the pads. The brake body, which is not exposed to centrifugal forces, can be manufactured in both an aluminium single-piece version and a two-piece version with an aluminium body and a cast iron pipe jumper. In order to improve heat dissipation, the aluminium part can be equipped with heat dissipating fins. In other words, the contact surface between the medium and the caliper is increased.

The operating principle is simple: when the brake pedal is pressed down, the main cylinder is activated (which may or may not be equipped with a booster), increasing the pressure throughout the system. When this pressure is applied to the piston, it pushes the internal brake pad against the rotor. Due to the fact that the pressure applied and the enclosed fluid act uniformly in all directions, a reactive force is simultaneously applied to the body. This force slides the body along the guide bolts and pulls on the external pad against the rotor. The braking effort is



Sliding caliper

therefore equal on both sides. The adjustment of the separation of the pad from the rotor after completing the braking process is achieved in a similar manner to that of the fixed calipers, by means of the controlled deformation of the piston seal.

In this type of caliper, in addition to the routine checks of the piston and its air tightness elements, it is also very important to verify that the caliper guides slide properly in order to guarantee the equal distribution of effort on the two brake pads of the caliper.

5. PIPES AND HOSES

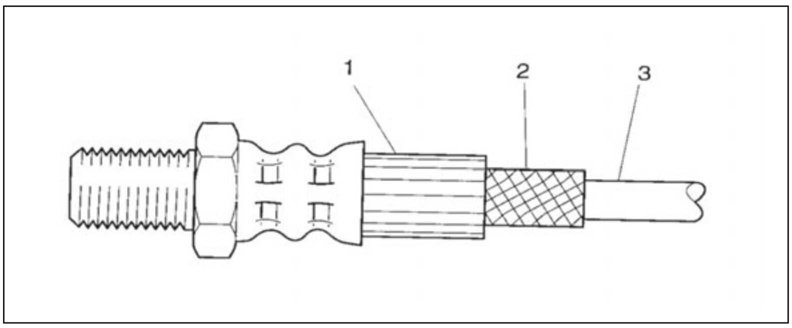
The pipes and hoses are responsible for channelling the brake fluid, withstanding the internal pressure of the fluid, and must also resist environmental aggression and other aggressive agents in the surroundings.

The brake pipes are normally steel pipes and are often covered with polymer to resist corrosion; they usually have a nominal bore of 2.5mm and an external diameter of 4.5mm. Each end of the pipe is fitted with an individual or double cone so that it fits into the component in which it is placed, and has a male or female pipe nut fitted, as necessary.

The flexible pipes are constructed in layers. Their coating must be resistant to mineral oil and the outside to hard particles and damage caused by stones, water, salt and other contaminants which may be encountered on the road. The product used is a polymer mixture of ethylene propylene diene monomer (EPDM).

A fabric made of multiple layers of rayon is used for the two reinforcement layers, which resist the pressure of the flexible pipe. The flexible brake pipes are designed to work at a pressure of 100 bars; their breaking point is 5 times greater.

The internal membrane of the flexible tube must be resistant to brake fluid (1). The material used is EPDM, as it is not very permeable. The material of the internal layer is made of rayon, as it has very good qualities of resistance to internal pressure (2). Some flexible tubes have plastic or stainless steel cases rolled around them in order to provide additional protection against the bending of the pipe in other components (3).



Brake hose

6. BRAKE FLUID

The brake fluid is a polyglycol solution which contains a viscosity-adjusting dissolvent (ethylene glycol), an antioxidant and an anti-corrosion additive. The quality of the brake fluid is similar to that of antifreeze. The common term of "oil for brakes" is therefore incorrect, as one should talk in terms of brake fluid.

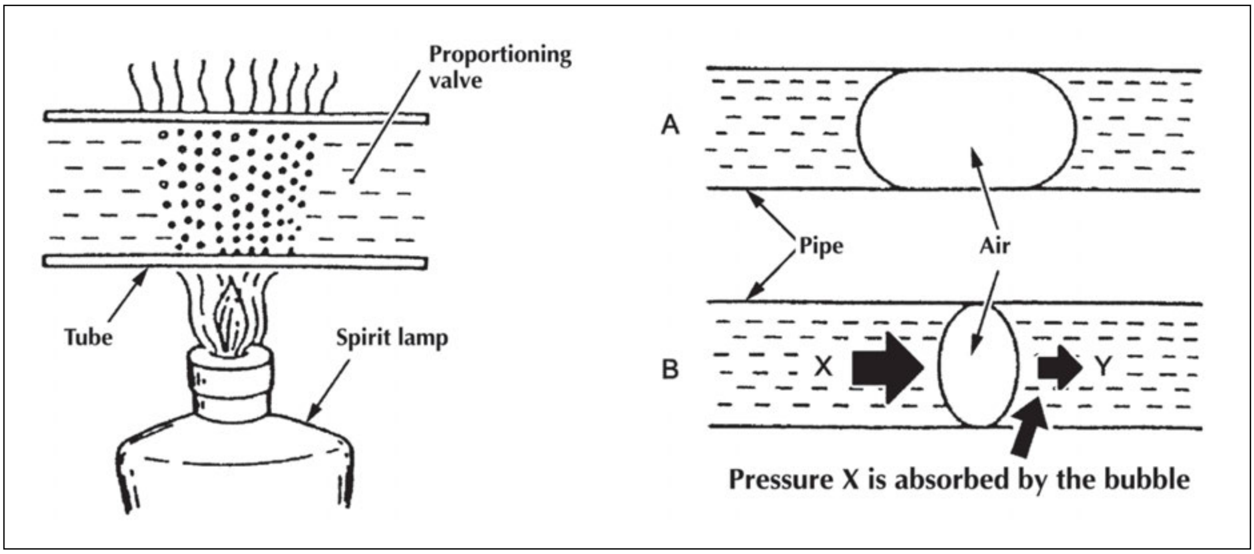
The brake fluid is an element which when pressurised by the pump, pushes the caliper cylinders against the pads, thus causing the braking action to take place. It tends to be forgotten about by car users, as very few drivers give this element the importance it deserves. As we will see below, its characteristics are those which guarantee proper braking, but it is an element that degrades with use and the passing of time and must be replaced.

The main properties of brake fluid are as follows:

- It is incompressible (like all fluids).
- Its minimum boiling point must be above 230ºC. It will thus remain in a liquid state, without boiling, when the braking demands are very high.
- It must have low viscosity in order to move quickly around the circuit.
- It must be a lubricant so that the movable elements of the brake system with which it comes into contact do not seize up.
- It must be chemically stable.
- It must maintain viscosity and fluidity in accordance with the temperature of the system.
- The boiling point of the brake fluid must be sufficient to ensure that vapour block does not occur.
- The brake fluid must not have the characteristic of attacking rubber materials. Specifically it must not cause the materials to expand or contract.
- The brake fluid must not corrode metals.
- The hygroscopicity of the brake fluid must be low.

A state of vapour lock means an interruption in the transmission of pressure to the brakes due to vaporisation (the formation of an air bubble in the route of the system). If the brake fluid boils and is vaporised due to the heat, vapour bubbles will form. If this occurs during driving, it will be possible to press the brake pedal down to the floor as the brakes will cease to be efficient.

Most of today's brakes fluids comply with all of the requirements demanded of them. However, due to the composition of the elements it is made up of, brake fluid also has a property which means that it should be replaced every 2 years or 70000km. This property is its hygroscopic property; in other words, it has a great capacity for absorbing water. In damp environments, it may well be necessary to change the fluid before the aforementioned periods.



Why is the hygroscopic capacity of brake fluid negative?

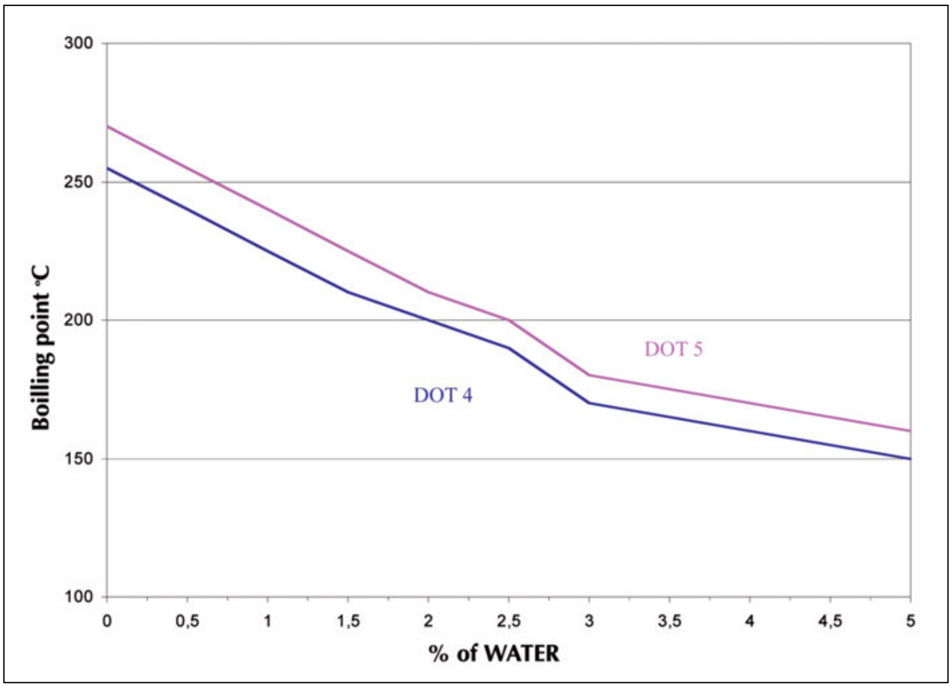
It might be thought that when there is water in the brake system there would be no reason to modify the qualities of the fluid, as it is also a liquid. However, this is not the case as even though the water is in a liquid state, it corrodes the elements of the brake system with which it comes into contact. Although the main problem of the existence of water in the brake system is that when the temperature of the liquid exceeds 100ºC, the water evaporates and turns into water vapour (a gas, which is compressible), meaning that the pedal can be pressed to the floor, as all the pressure that we are introducing into the system will be used to compress that water vapour and not to act on the brake pads. In addition the existence of water in the system as is seen in the diagram reduces the boiling point of the fluid.

Brake fluids are currently divided into two groups according to their characteristics. Two standards of brake fluid can therefore currently be marketed.

- DOT 4: the boiling point of which is 255ºC. Used in rotor/drum or rotor/rotor systems without ABS.
- DOT 5: the boiling point of which is 270ºC. Must be used for high performance vehicles and those which are equipped with ABS systems.

Both standards of fluid can be mixed with each other but this is not recommended. Although it is possible to mix them it is advisable to check the vehicle maintenance guide to find out what kind of fluid the vehicle uses if it needs to be refilled. When the brake fluid is replaced it is advisable to clean the circuit with alcohol so that the new fluid maintains all of its properties. In addition, the brake system must be bled after any modification is made.

It should be remembered that vehicles which have oil-based hydraulic suspension also use this same liquid as brake fluid. This type of fluid is known as LHM and it is very important to take into account the fact that DOT brake fluid must not be mixed with LHM, as it would ruin the whole system.



Comparison of the effects of water in the different types of brake fluid

CHAPTER 4

BRAKE PADS

1. A BRIEF HISTORY OF FRICTION

The appearance of self-propelled vehicles at the end of the 19th century meant that there was a need to provide them with a system for stopping whenever required by the driver. The first solution provided was the adaptation of the brakes of horse carriages in the first cars, as the speeds reached by mechanical traction vehicles were relatively low. These systems consisted of the guide activation of a lever which moved a brake shoe, which rubbed against the tread of the wheels, thereby producing the friction necessary to effectively decelerate or stop the vehicle.

In 1897, Herbert Frood implemented the first friction lining based on the use of cotton fibres, plaited in the shape of a belt. This was all linked together by means of bituminous solutions and brass wires. The material was not only used in the brakes of horse carriages, but also in some of the cars of the time, achieving acceptable results. Logically it had some limitations as the use of a natural fibre such as cotton meant that above 150ºC it lost the properties of friction and broke. This disadvantage became apparent immediately and only ten years later asbestos fibres were introduced into the formulation. This laid the foundations for friction materials in the following decades.

Chrysolite asbestos fibre was chosen for most applications. The asbestos fibres were easy to weave in the same way as cotton, which made it easy to replace the cotton fibres. Its greater mechanical resistance, resistance to temperature, flexibility, excellent friction properties and compatibility with resins and other binding substances made asbestos fibre the best of the components for friction applications. The inclusion of brass and other wires in the fabric added physical resistance and modified the frictional behaviour of the material.

For sixty years, friction materials of this type have made an enormous contribution to safety in cars, lorries and all kinds of moving vehicles throughout the world.

At the beginning of the 1920s, chemists began to study the replacement of the plaiting of the linings with moulded parts. They began using cut chrysolite fibres, which were very abundant and had a low cost. One of the first creators of brake linings was a Mr. Blume, in 1926. His formula has a number of very interesting similarities to the first asbestos formula developed. The original formula was based on brass wires, reinforced with asbestos fabric and joined together by an oil and asphalt rubber composite. The new moulded formula used the same asbestos, but the fibres were shorter than those used in the asbestos fabric. The brass wire was replaced with brass particles, and the original asphalt with linseed oil and a special bituminous coal which provided a high degree of volatility and gave of a low level of ashes. Many of the subsequent advances achieved were merely improvements added to this original concept.

In the 1930s, chemists began research into flexible resins with greater heat resistance. These new materials, along with the dry mixing process, opened the way to new and much more sophisticated components and with it the new world of friction materials that we are all familiar with today.

At the same time, other pioneers in the development of friction material had their origins in the rubber industry. The plaited cotton and subsequently the plaited asbestos were covered with rubber composites which were then piled in layers until the required thickness was obtained. All this was achieved thanks to the contribution of machinery typical of the rubber industry. Later on, asbestos fibre and rubber compounds were introduced which could be laminated and folded or extruded, also using conventional rubber machinery.

In the 1950s, a new formulation was implemented which contained new resins which bound metal shavings together, thereby paving the way for the appearance of pads on a metal base. This formulation was the result of the great success that metal friction materials had achieved in industrial and aeronautical applications. These new metal materials were a mixture of resins with steel wool and graphite. These types of formulas were used a lot in the 1970s for the manufacture of pads.

In the 1960s, as advances were made in the design of vehicles and it became necessary to improve the brake systems, many friction material companies began to look for alternatives to asbestos as the main component of rotor brakes. Asbestos was a material with its own limitations; it was an exhaustible resource of variable quality and its price was rising. As an alternative, the use of fibreglass, metal fibres and most recently synthetic carbon fibres was considered.

At the same time, questions began to be asked about the effect on health of the use of asbestos. Many manufacturers stopped working with this material due to the problems associated with it. All this meant that semi-metallic friction materials began to be used more in the 1970s for the manufacture of rotor brakes.

Semi-metals are far from ideal materials for any application. Friction materials with a high metal content are better heat conductors than the compound asbestos materials and this can lead to problems such as, for example, the excessive transfer of heat to the caliper and the brake fluid, which may begin to boil.

The development of new friction materials continued in the 1980s. The appearance of front wheel drive, the reduction in the size of wheels and the improvements in aerodynamic design are just some aspects of the development of the car industry which have entailed new demands in the world of friction materials over the last 20 years. The increase in the heat generated during braking poses additional problems for friction engineering and for those formulating new friction materials. A new generation of products is thus being developed with lower thermal conductivity than semi-metals, which means a decrease in the transfer of heat to the brake fluid.

In the 1990s, a new trend appeared in the development programmes of the main vehicle and friction material manufacturers with the aim of replacing the heavy metal contents of friction materials (antimony trisulphide, lead or galena sulphide, molybdenum disulphide, copper fibres and copper components, as well as silicon fibres) with non-toxic compounds, in order to avoid the negative impact of these materials on the environment and humans. Work was carried out on an organic material which did not disintegrate at high braking temperatures and maintained its friction characteristics in a wide range of temperatures; a material which accepted wear without damaging other surfaces. We saw the appearance of a new generation of friction materials with superior performance which were more respectful of the environment, as well as the people who came into contact with these materials on a daily basis.

However, there are still products on the market which contain asbestos, and it is recommended, given their carcinogenic properties, that they be handled according to the strict safety rules for handling products containing asbestos which are clearly defined in all countries.

2. COMPOSITION

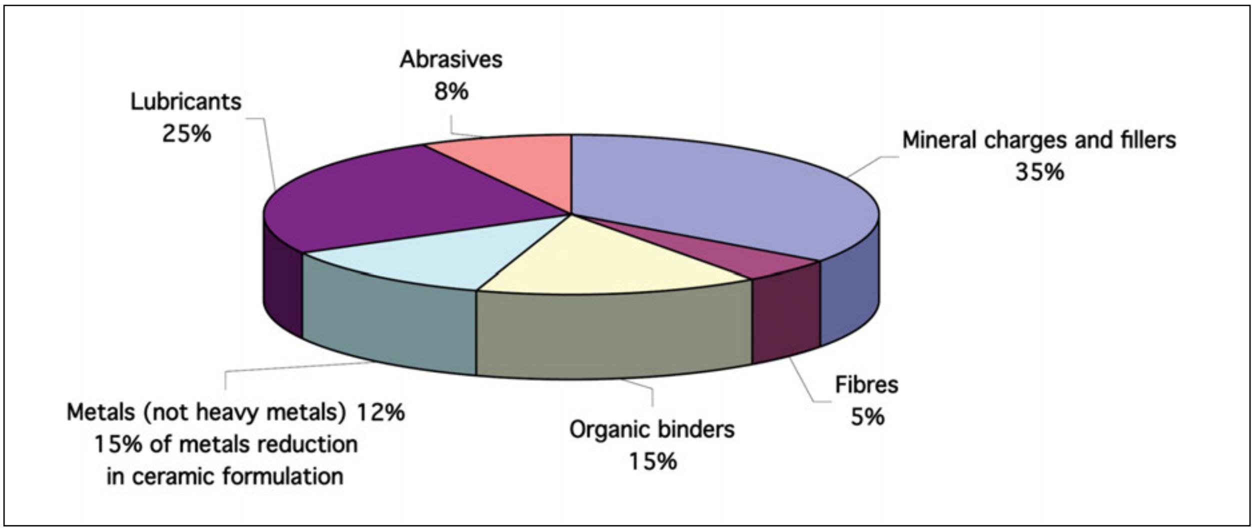
The requirement for asbestos to be eliminated meant an important change in the formulations. Asbestos was a fibre which formed the basis of all formulations as it was capable of providing the qualities required for any friction material.

However, although the first “asbestos-free” materials which appeared in the market were of inferior performance and lasted less than those with asbestos, the “asbestos-free” products have today overtaken them in relation to all the requirements demanded of friction material.

To a greater or lesser extent, most friction manufacturers currently use the base shown below:

Any compounds in Remsa formulation as twaron, rock wool, green chrome oxide, graphite, etc.

- ❏ FIBRES: the fibres are the elements responsible for bringing together and binding the other elements. In other words, they provide the “framework” of the brake pads and through their many branches join together all the other elements. There are two main types of fibres: synthetic and mineral. The most common ones in the friction field are glass fibres, aramid fibres, rock wool, etc.
- ❏ MINERAL FILLERS: the mineral fillers responsible for giving mechanical consistency to the whole unit. In other words, they provide resistance to abrasion, resistance to shear strenght, etc. They are also responsible for providing resistance to high temperatures. The most common ones are barite, magnesite, talc, mica, carbonate, feldspar and others.



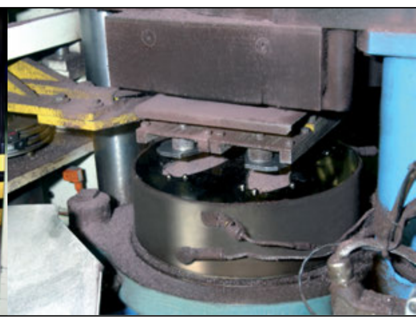
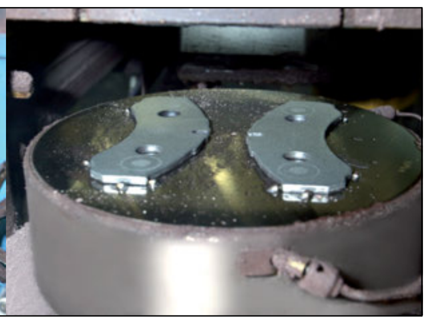
Average composition of advanced friction material

- ❏ METAL COMPONENTS (FOR SEMI-METALLIC FORMULATIONS): added in powder or shaving form in order to achieve the homogenisation of the coefficient for the transfer of heat from the pad to the caliper. The most common components include brass, copper and bronze. These ones don't appear in ceramic style formulations as Remsa has developed resucing more than 15% of metalic compounds in the formula.
  However, a large part of the metal components used in friction materials have harmful effects on health and it is therefore recommended that the legislation relating to products containing such heavy metals be strictly followed, for instance in Europe the heavy metals components were elimitated in 2003.
- ❏ LUBRICANTS OR COEFFICIENT MODIFIERS: responsible for causing the friction coefficient to vary, normally downwards, depending on the operating temperature range. They are used in powder form and are usually graphites, cokes, sulphides, anthracites, etc.
- ❏ ORGANIC MATERIALS: responsible for agglomerating the other materials. When they reach a certain temperature they flow and bind the other components until they are polymerised. The most important ones are the thermal-hardening phenolic resins, although different types of rubbers, waxes, oils, etc. are also used.
- ❏ ABRASIVES: their main function is to increase the friction coefficient. They also renew and clean the surface of the rotor allowing the formation of the intermediate layer also known as the third layer.

3. MANUFACTURING

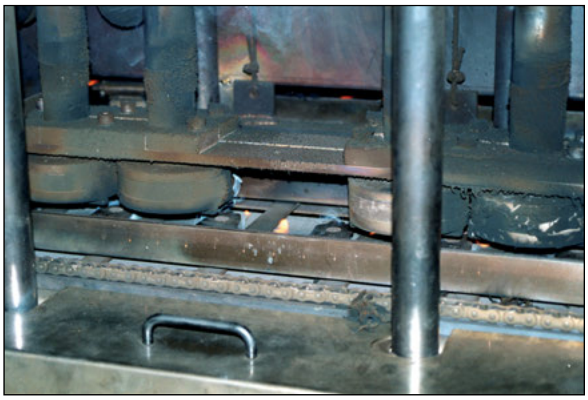
The manufacture of friction material is a fairly standardised process. The process variables are those defined by each manufacturer according to the type of materials used; in other words, the composition defined. Broadly speaking, the fundamental steps which must be followed when manufacturing are as follows:

- THE MIXING PROCESS: One of the most important steps within the manufacturing process, as its aim is to mix all the components homogenously. In order to achieve a good blend of the mix, the mixer is equipped with a central shaft which causes the components to turn in figures of eight whilst on another shaft two mixing blades blend the mix. In this process, one of the critical factors is the time that the different materials spend in the mixer, as this period has to be defined according to the type of fibres that are going to be mixed. Each fibre has an opening time; in other words, a period in which it is as long as possible. What then happens is that the fibres are shortened and will not therefore carry out the function described above.
- HOT PRESSING: the aim of hot pressing is to bring together the different components. On the one hand, with the pressure applied a reduction in volume is achieved, but the temperature means that the resins are also melted so that they flow through all of the material, binding the different elements. This process has associated pressing cycles; in other words, the press will act on the pads for a certain amount of time, and will then allow the gases to escape. This phase is when the bases are attached to the friction material. This takes place for two reasons: firstly, the base has an impregnated resin which achieves the adhesion of the material. Secondly, there are through-holes in the bases whose function is to contain the friction material which flows in order for the friction material to be completely fixed to the base. The typical pressing time varies from 5 to 6 minutes according to the formula used to allow the curing of the resins in the press.
- CURING: the curing process is carried out in furnaces. Its main aim is the complete polymerisation of the resins in order for the material to be completely compacted and to lose any existing content of volatiles. This process is also a function of the time and the temperature which is reached in the different phases. This means that the pads go through a cycle of different temperatures in which they spend a certain period of time. In a flash moulding press style or 2-3 minutes if the press operation is done in a automatic deep moulding press.
- SCORCHING: in this last phase, the friction material rises to temperatures of 500ºC or more under the effect of a hot plate or a flame. In the latter process a large part of the remaining organic materials is eliminated, the

polymer (resin) is graphitised and the brake pad acquires its definitive characteristics. This is an expensive and delicate process and as a result very few manufacturers incorporate it into their manufacturing processes.

- MACHINING OPERATIONS: In this phase, the pads go through different machining processes in order to adapt them to the dimensional characteristics required by each application. In other words, they are rectified in order to achieve the necessary friction material thickness. Another of the processes that they may undergo is the production of cavities or slots, as well as chamfers.
- FITTING OF ACCESSORIES: During this phase all the complementary elements are added to the pads, such as the springs, alarms, etc.



- MARKING AND PACKAGING: the pads are now completed; the only thing left is to mark and packaging them for the use of the different customers.

4. BASIC CHARACTERISTICS OF BRAKE PADS

The basic requirements of friction material are those established by the application of the product. The most important are as follows:

- ***An adequate and stable friction coefficient at any temperature and pressure range.***
- ***Maintaining a balance between abrasion and resistance to wear.***
- ***A certain amount of compressibility, when cold and hot, which causes the material to absorb vibrations and irregularities from the surface with which it is in contact.***
- ***Good resistance to collisions and shear stress.***

In order to fulfil all these requirements, each manufacturer implements its own formulations, which are tested over and over again until the results which offer the required quality are achieved.
As show on the next pages are different components which may be included in brake pads.

UNDERLAYER:

The underlayer is a layer of material whose function is to attach the friction material to the back-plate as well as to reduce the temperature reached by the caliper. This layer of material has its own formulation as its requirements are those expected of friction material, but its function is to join the layer of friction material to the back-plate. It also varies the thermal conductivity of the friction material so that the heat does not pass through it and the brake fluid does not heat up in the case of friction materials of high thermal conductivity.

In short, it is an added element which may involve additional risks. If it can be left out of the process, it is therefore advisable to avoid having to use this element.

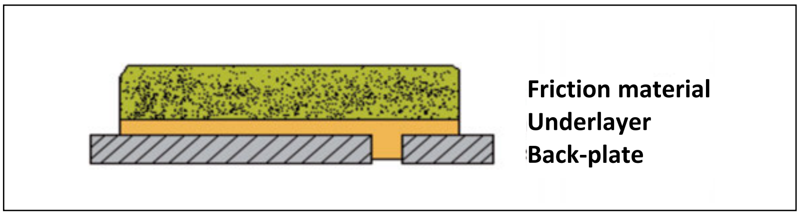


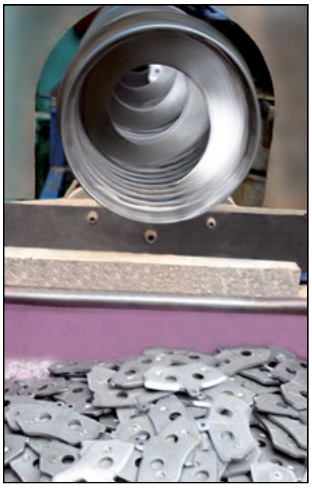
Diagram of a brake pad with UNDERLAYER

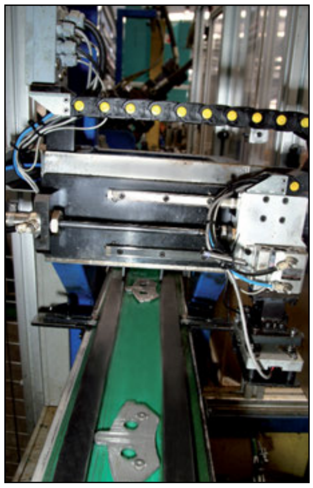
BACK-PLATE:

The back-plate is a metallic element whose function is to hold the friction material in the pad carrier of the calipers. Its most important characteristic is that it must be as flat as possible in order to prevent cracks from forming between the back-plate and the friction material during the hot pressing process and the subsequent curing of the pads.

The back-plates are manufactured by tooling a metal ring of the required thickness. Depending on the complexity of the refferences, they will be manufactured in several steps, although it is one of the most automated processes in the manufacture of brake pads.

Metal base

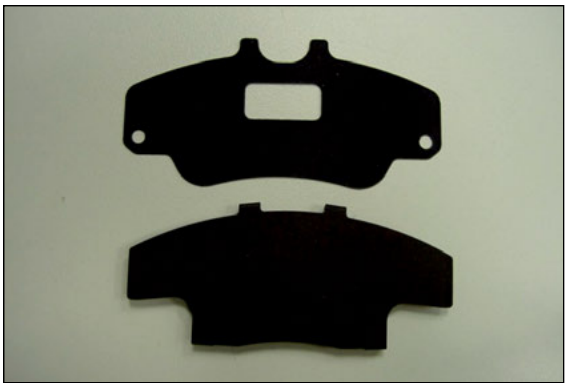


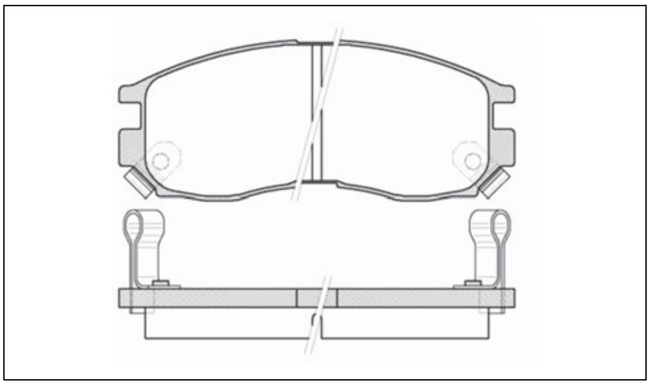


The back-plates are painted with a high resistance varnish in order to prevent corrosion over time. The preparation of the metal back-plate in order to guarantee the proper adherence of the friction material is a critical phase of the manufacturing process.

ANTI-NOISE SHIMS

The anti-noise shims are accessories the main function of which is to absorb any vibrations which may occur in the contact between the pad and the rotor, preventing noise from occurring. Different materials are used, such as glass fibre sheets, metal sheets, etc. and a different type of shim is specified for each application depending on the type of vehicle in which the pad is to be fitted.





Anti-noise shims

The method of attaching them to the back-plate tends to vary depending on the type of material used in the anti-noise shim. There are shims attached by means of a phenolic resin which have to be compressed against the back-plate, and the whole unit is subjected to a temperature of approximately 150ºC. Other shims are riveted to the nubs of the back-plate. Another possibility is for the shim to be fixed to the back-plate by means of pins and fitted into two of the nubs on the back-plate to prevent it from moving.

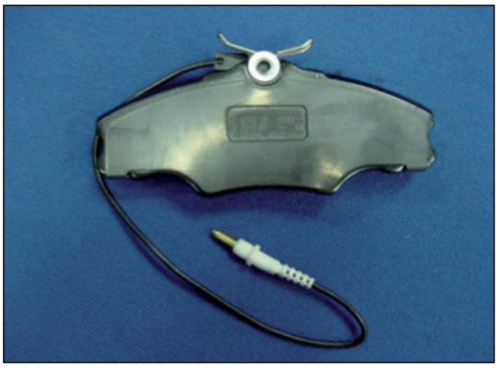
These shims enable the compressibility of the brake pad when cold to be increased with the resulting positive effect on squeal without significantly increasing the compressibility of the brake pad when hot, which could lead to excessive brake pedal play.

OTHER ACCESSORIES

In order to absorb the vibrations to which the pads are subjected in the caliper under braking, they have a series of accessories known as springs, which are manufactured from metal rings. These types of elements depend on the geometry of the pad in the attachment system. There are other types of springs which are situated in the caliper itself but whose function is the same as those situated in the pads. In short, they allow a slight movement of the pads when braking which causes the vibrations which occur to be absorbed.

One of the types of accessory included in the pads are the wear alarms. The function of these elements is to warn the vehicle user that their pads are about to reach the end of their useful life and must be replaced. There are various types:

ACUSTIC WEAR SENSORS: This kind of wear sensors are small rings which are housed in the sides of the back-plate and protrude by approximately two millimetres from the friction surface. When the pad has worn down and there is only 2mm of friction material left, this small hoop rubs against the rotor and a constant squeal occurs which warns the driver that their pads must be replaced.

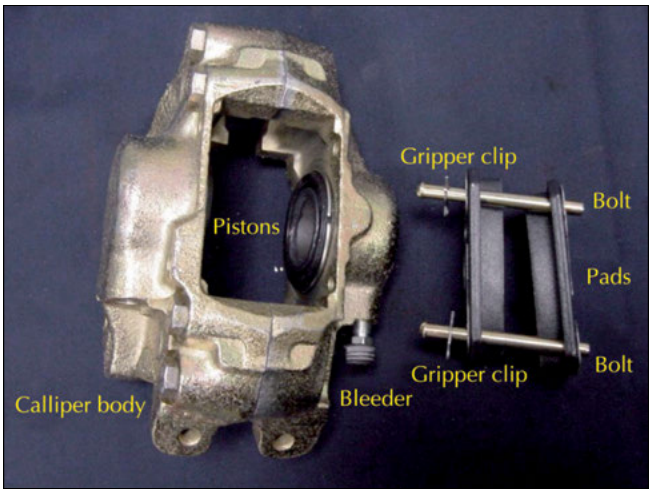


Pad with warning light

ELECTRIC WEAR SENSORS: the electric sensors are made up of a conductor cable with a polymer head which rubs against the rotor, when the pad only has 2mm of friction surface left, and wears down until contact is made with the rotor, creating a mass which completes the circuit. This causes a warning light in the panel to come on which tells us that we need to go to a garage to change the pads.

5. CALIPER/PAD UNIT

In the unit shown below all the elements that make up the caliper/pad unit can be seen more clearly.



Breakdown of dual piston calliper parts

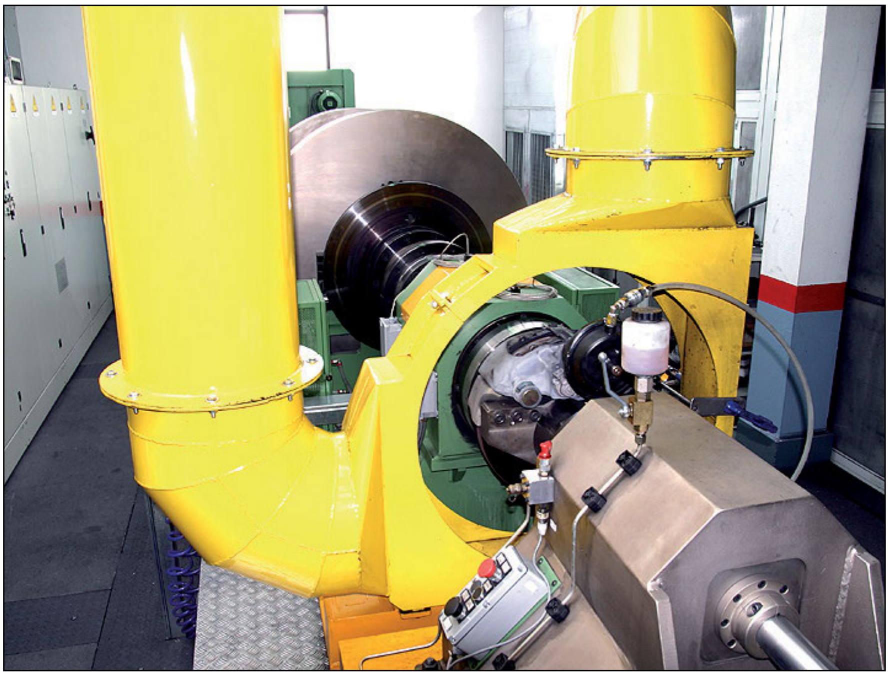
1. *Caliper body: provides rigidity and supports the pads.*
2. *Pistons: push the pads against the rotor.*
3. *Bleeder: opens the system to release air from the circuit.*
4. *Gripper clip: retain and prevent the pins from coming out.*
5. *Pins: hold the pads and act as guides for them.*
6. *Pads: rub against the rotor.*

6. PARAMETERS WHICH DEFINE FRICTION MATERIAL.

The basic parameter which defines any friction material is its friction coefficient (m). During the development of new formulations, the friction coefficient is tested in inertia dynamometers, as well as in pressure meters or Krauss dynamometers. Once this phase has been completed tests are carried out directly in vehicles equipped for the acquisition of the data produced by the test.

The fundamental tool is still the inertia dynamometer. These are fully sensor-equipped test stands, to which the brake system intended to be tested is coupled. These stands are controlled by powerful computer systems which are capable of measuring any parameter during the test including the rotor temperature, friction coefficient, circuit pressure, turning speed, deceleration, etc. The inertia dynamometers are essentially capable of reproducing the forces generated in a vehicle during the braking process. This means that an accurate simulation of the working conditions of the brake system is achieved, particularly with regard to the friction material during braking.

The basis of the inertia dynamometer is the conversion of the kinetic energy of the vehicle into rotating kinetic energy. When braking takes place it therefore converts the kinetic energy carried by the vehicle into heat energy, thereby reproducing the energy conditions associated with the vehicle.



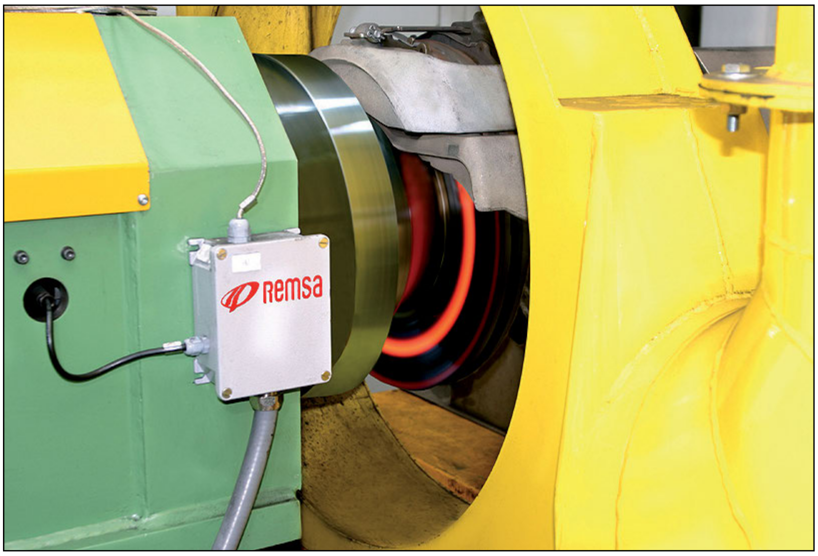
Inertia dynamometer

$$\textit{Kinectic energy of vehicle } E_c = \frac{1}{2} M \cdot v^2 \qquad \textit{Units } [kg] \cdot \left[\frac{m}{s}\right]^2$$

$$\textit{Kinectic energy of dynamometer } E_c = \frac{1}{2} I \cdot w^2 = \frac{1}{2}\left[\frac{1}{2} \cdot M \cdot R^2\right] \cdot w^2 \quad \textit{Units } [kg] \cdot \left[\frac{m}{s}\right]^2$$

Where:
M = Mass of the vehicle (kg).
v = Speed of the vehicle (m/s)
I = Moment of the inertia masses of the dynamometer (kg/m^2).
v = Angular speed of the dynamometer (1/s).

As it is possible to equate the two energy expressions (they are measured in the same units), we can calculate the inertia in the dynamometer necessary to accurately simulate any type of vehicle, as well as any type of situation on the road. All of the advantages offered by working with the dynamometer can thus be exploited.



Inertia dynamometers are made up of an *electric motor* which is responsible for providing the necessary speed for the inertias; the necessary power of the motor is that determined by the inertia that it is capable of moving. The *inertia masses* are rotors of different diameters which determine the dimensional characteristics of the vehicle to be tested. In other words, a vehicle with a particular mass when it is moving carries an energy which has to be dissipated when braking. The inertia masses therefore accumulate the same energy as the vehicle that it is intended to simulate. The inertias are naturally linked to the electric motor by means of an axle. At the end of this axle is a flange where the brake rotor is fitted. The caliper intended to be tested is fitted on the fixed headstock, as well as the brake pump and the hydraulic system which controls the pump.

The tests which can be carried out with the dynamometer are very varied as the software which controls the stand can be programmed so that the required test can be carried out. There is a range of internationally recognised tests which are used by different companies as standard test levels.

The tests are divided into different phases in which the friction material is tested under different working conditions. A basic test could be considered to be made up of the following phases in a standard testing programme **(AK-Master):**

- *Bedding-in stage*. The tests carried out make clear the need for bedding-in, just as we must bed in new pads in our vehicles after they have been changed. The bedding in is carried out at temperatures below 100ºC, the pressure varies from 15 to 45 bars and the speed range is from 100 to 30km/h. The friction coefficient is measured throughout the stage in order to monitor the behaviour of the material during the initial braking processes. This stage is made up of 100 braking processes.
- *Pressure sensitivity stage*. By varying the circuit pressure, the friction coefficient that the material is capable of providing is verified at different speeds. In an initial sub-stage, braking processes are carried out at 40km/h at pressures ranging from 10 to 80 bars. In the next sub-stages, the speed is 80, 120, 160 and 180km/h with the same braking processes; in other words, maintaining the range of pressures.
- *Fading stage*. This stage is usually repeated a couple of times during the process, in order to verify what happens to the coefficient if two fading processes occur. The fading test is made up of 20 braking processes in which the requirement is to achieve average deceleration of $4 m/s^2$ at different temperatures which range from 100ºC in the first braking process to 550ºC in the last braking process. Each of the 20 braking processes is carried out when the specified temperature is reached. These temperatures are increased by approximately 30ºC in each braking process. The pressure in the circuit is that which is necessary to achieve average deceleration of $4\ m/s^2$.
- *Pressure sensibility at high temperature stage*. This stage is the same as the sensibility to pressure phase but with an initial system temperature of 500ºC.
- *Characteristic analysis stages*. These stages measure the friction coefficient in normal braking conditions; in other words, at a pressure of 30 bars, an initial temperature of 100ºC and with a speed interval of 80 to 30km/h. 18 braking processes are carried out during which the friction coefficient is measured. They are carried out after each of the phases described above.

The ideal scenario for good friction material would be for the friction coefficient to remain constant at μ=0.4 for any range of use, in relation to temperature, pressure or any other parameter. It should also have very little wear and not damage the other surface with which it comes into contact. However, this is unrealistic as the friction material is subjected to many changes, as we have already seen.

Friction material is not only characterised by the friction coefficient but also by other characteristics which are intrinsic to the material. These characteristics must be maintained within certain limits to ensure that the material fulfils its primary function.

DENSITY

The density r of the material of the pads is the relationship between the mass of the friction material divided by the volume it occupies. It is an important figure as it can give us an idea of the pressing that takes place during the manufacturing process and also of what the life in service expectations might be.

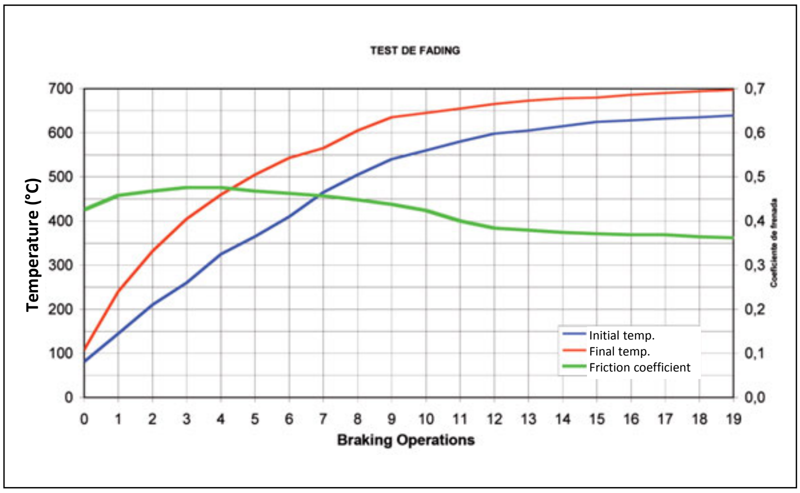
POROSITY

Porosity is understood as the relative volume of the proportion of cavities in the material. This includes pores, air pockets and any cavity in the material. The proportion of cavities must be lower than 5% of the surface of the pad and should not affect its profile if the pad is not to be rejected. High porosity may cause premature wear and low porosity may lead to squeal.

SHEAR STRENGHT FORCE

The shear strenght force is the resistance of the friction material when separated from the back-plate when a tangential force acts on it. This is one of the most important values as under braking the brake pads are subjected not only to normal forces against the rotor but also to large tangential strains which are those generated by the rotor as it attempts to drag the pads in the direction in which it is turning.

The minimum acceptable value for a shear stress test is 250N/cm^2, in accordance with Regulation 90. This pressure is equivalent to developing a force of 1250kg in an average type pad, with an area of 50cm^2. If this characteristic is not fulfilled it is necessary to take corrective measures which achieve greater adherence between the back-plate and the friction material. The main actions aimed at correcting this defect are the use of a different adhesive, even varying the friction material in order to improve its flow through the holes in the back-plate and for its adhesion to the back-plate to be better.



Graph obtained during the fading phase

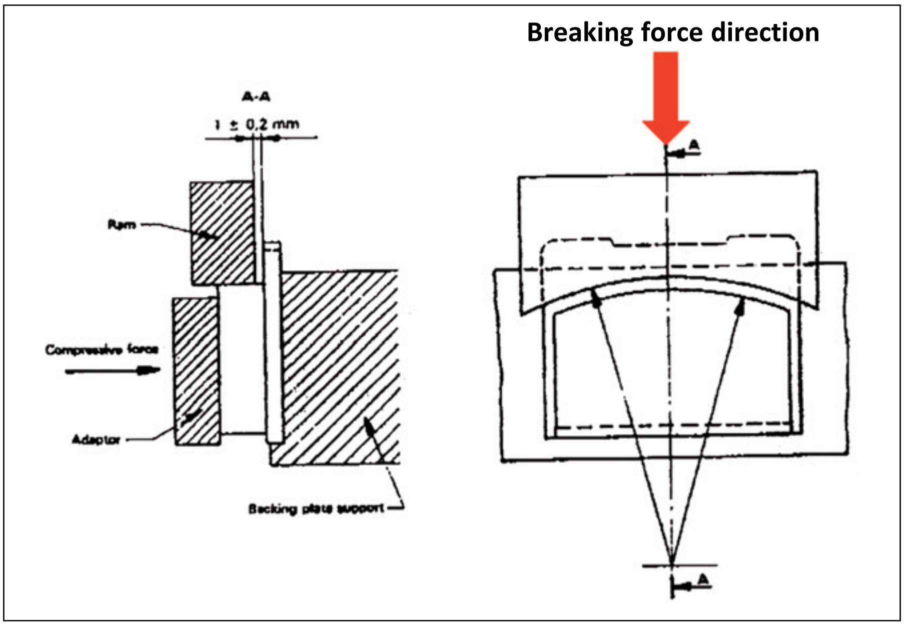


Diagram of the shear stress test

It is important to mention not only the breaking point or shear stress maximum pressure withstood by the material but also its adhesion to the metal back-plate, as once the friction material has been separated from the back-plate there must be material left attached to the back-plate which covers more than 80% of the surface of the back-plate. If this is not the case, the appropriate measures should be taken, as described above.

The diagram shows how the breaking force must be applied in the machine. It is important for the radius of the tool that will push the friction surface to have the same radius as the pad in order to comply with the stipulations of Regulation 90.

The test described above is used as a control test, both in the development of new materials and in the usual quality control carried out throughout the production process.

COMPRESSIBILITY

Compressibility is the change in thickness of the pads due to the application of a normal force to the surface of the pads. This test is carried out in two different conditions; initially at room temperature, which is known as cold compressibility, and subsequently by placing the pad on the side of the friction material for 10 minutes against a surface at 400ºC, or what is known as the hot compressibility test.

Compressibility machine

When the cold compressibility is greater than 2% the friction material should be modified to ensure that such a large reduction in thickness does not occur in the material. During the hot test the maximum compressibility value must be less than 5%. If this value is exceeded corrective measures must again be taken as the maximum cold and hot limits are defined in Regulation 90.

It should be pointed out that the compressibility of the brake pads is one of their fundamental characteristics as with a certain level of compressibility they absorb vibrations between the rotor and the pad, thereby reducing the damaging effects of vibrations on the brake system which normally result in noise. On the other hand, excessively high compressibility may lead to excess pedal play.

THERMAL CONDUCTIVITY

Thermal conductivity is the physical property of the materials by which they have the capacity to transmit heat through their interior. In the case of brake pads it is very important for the thermal conductivity to be able to expel the heat towards the exterior of the pad, but it must be controlled as if this heat passes through the metal back-plate to the caliper and from there to the brake fluid there could be a loss of braking efficiency due to the brake fluid boiling.

The thermal conductivity values vary significantly in the formulation of friction material as if the pads are semi–metallic (those which have a high content of steel wool, copper, brass or other metals), their thermal conductivity will be higher as metals are better temperature conductors. In semi-metallic formulations it is therefore very important to install an underlayer which prevents the transfer of heat to the brake fluid to ensure that the brake fluid does not boil. In friction materials with an organic back-plate the thermal conductivity will be lower and in most cases there will therefore be no need to use an underlayer.

SUMMARY

The factors described above may even contradict each other and success in the development of a quality brake pad thus depends on the criteria of the manufacturer with regard to how to assess and consider the effects of these factors in order to offer users the best possible product in accordance with their expectations.

CHAPTER 5

BRAKE ROTORS

1. BRAKE ROTORS

The brake rotors are the surface that the pads interact with in order to slow down the vehicle, due to the rotor turning along with the wheels. This friction between the rotors and the pads causes the transformation of kinetic energy into heat energy, leading to a reduction in speed.

The brake rotors must not only produce the transformation of energy but also transmit the heat produced into the atmosphere as quickly as possible, as otherwise the operating temperature of the system would be very high, leading to its consequent breakdown.

The material chosen to manufacture the brake rotors is nodular grey graphite cast iron, as it guarantees stable performance throughout the life of the rotors. There are also rotors made up of compound materials in a carbon matrix, which are used in top competition and in brakes for planes, although their high cost means that they are not feasible for normal vehicles. brake rotors are currently being developed in aluminium with a silicon carbide back-plate, as their lower weight makes them attractive. However, their poor heat dissipation means that at present they are unviable as they require a significant increase in size which nullifies the advantage of the low weight.

The basic characteristics of the casting of the rotors can be seen in the table below.

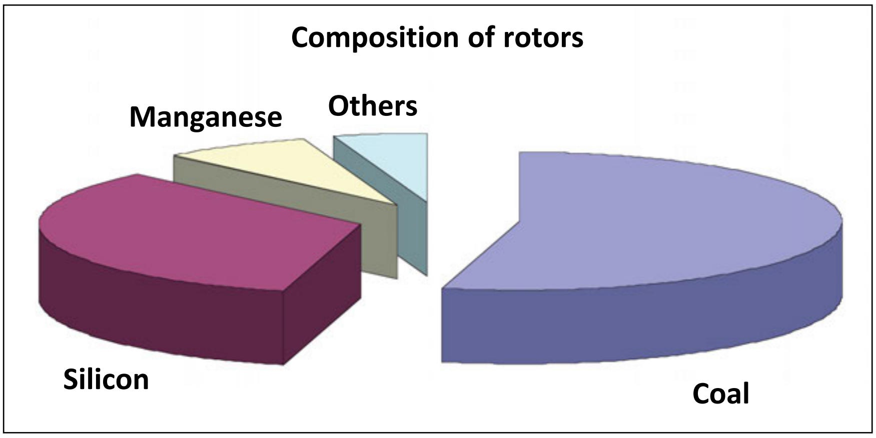
Physical properties	Values
Resistance to traction	$240 N/mm^2$
Hardness	170 – 250HB

Brake rotor

The basic composition of the rotor material is nodular grey graphite cast iron, which contains between 92% and 93% of iron. In addition to iron, other basic components such as silicon, manganese and others guarantee the quality of the rotor, which is a critical braking element. The diagram shows the other materials, in addition to iron, which make up between 7% and 8% of the total composition of the rotor.

2. THE GEOMETRY OF THE BRAKE ROTOR

The geometry of brake rotors is always the same; in other words, it is a perfectly flat circular surface. The solutions that have been offered for improved dissipation of the heat stored by the rotor are shown below.



Composition of the rotors (Other components, excluding the 92% of iron)

Firstly, the different parts which make up a rotor will be described.

- ROTOR: the surface on which the friction action between the pads and the rotor takes place. It is dimensioned so that its dissipation power is around 250W/cm². However, this value may vary depending on the geometry of the rotor as if it is ventilated the dissipation power may be as high as 750W/cm². Above these values, damage may appear on the rotor, such as geometric deformations, cracks, friction material deposits and other causes of irreversible damage to the rotor.
- MOUNTING: The mounting is ensured by the central part of the rotor and is made up of a circular hole, which keeps the rotor in the centre of the wheel, and some holes situated around the bushing which enable the screws that attach the wheel to the bushing to pass through.
- BELL: The bell is the cylinder which joins the shoe to the mounting surface. In some cases the interior of the bell is used to fit a small mechanically actuated brake drum system which acts as a parking brake (Peugeot 406 or others).

- HEAT FILTER: The heat filter is a machined channel which separates the rotor from the mounting surface, thereby reducing the heat which passes from the rotor to the bell. This type of channel prevents excessive heating of the wheel rim and consequently of the tyre, which already suffers the effects of the temperature resulting from its own use.

As we have already seen, the operating principle of brakes is based on the fact that the kinetic energy carried by the vehicle must be dissipated in the form of heat. This heat is mainly accumulated in the rotors. However, the rotors obviously cannot store it indefinitely and it must therefore be dissipated into the atmosphere in an efficient manner. The simplest way is to generate a flow of air which, when making contact with the rotor, heats up and keeps the temperature of the rotor at reasonable values in order to maintain its mechanical integrity.

The rotors must fulfil two main functions: moving the air to the surrounding area as a ventilator does, and transmitting its energy to the atmosphere in the same way as a radiator.

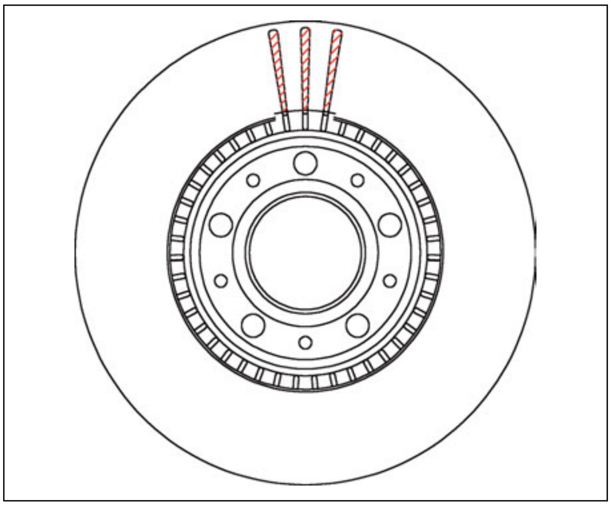
In order to fulfil the first of its functions, the geometry of the rotor itself means that it is possible for the air to flow from the bell to the exterior of the rotor. In addition, the speed of this air is greater the higher the temperature acquired by the air. This process is seen in solid rotors, which fulfil their function when there is a low or medium level of energy to be dissipated. When the heat energy dissipated increases, the surfaces of a solid rotor are no longer sufficient. Any attempt to increase its size would be limited by the size of the wheel and the unanimously adopted solution is therefore a ventilated rotor which enables increased heat dissipation in the same space.

The ventilated rotor is made up of two rotors separated by fins on its interior. These fins guarantee the cohesion of

Internal fins of a brake rotor

the rotor, allowing air to pass through its interior. They also mean that the cooling of the rotor not only takes place on the external surface of the rotor but also occurs on the interior. This exchange of energy largely depends on the shape and orientation of the fins, as in some cases the fins are opposed to the movement of the air in its interior and their utility is thus negative. There must therefore be a compromise between efficiency and the orientation/shape of the fins. They are generally radial and whether they are fitted on the left or right wheel does not therefore affect the self-ventilating properties of the rotor. There are some applications on the market in which the fins are orientated in such a way that they require these rotors to be fitted on one wheel or another, as their ventilation would not be effective if they swapped position.

One of the most significant improvements aimed at reducing the temperature reached by the rotor bell is achieved by means of a slot in the form of a channel in the area located between the bell and the brake shoe of the rotor, which we have previously identified as the heat filter. The section for the heat to pass through is reduced and the thermal gradient increases; in other words, the temperature difference between one side of the channel and the other increases, meaning that the bell temperature is lower. This is very important, as the heat which is transferred to the wheel rim and subsequently to the tyre rubber is lower, thus ensuring that the tyre carcass does not suffer excessively. A reduction in the deformation of the rotor is also achieved, as the bell temperature and its consequent thermal stresses are reduced.



Thermal channel of the brake rotors

In the ventilated rotors the manufacture of a different thickness between the shoes reduces their deformation. This is achieved by increasing the thickness of the rotor which is exclusively attached to the bell; as if the thickness of both rotors were increased the total thickness of the rotor would increase excessively with the required reduction in the thickness of the friction material.

The two-part rotors made for competition consist of a cast iron ring made up of brake rotors and aluminium alloy bushing. The two parts are attached by means of mounting fittings. During braking the rotor has two differentiated parts: the brake shoes (hot part) and the bell (cold part). This type of rotor solves the deformation problems as the brake shoes can be dilated without causing tensions which create cracks. In addition, this type of rotor allows the radial deformation of the rotors, preventing permanent deformations and tensions. It also means a significant reduction in the weight of the unit. However, given their high cost, these types of rotors are usually only used in competition although they are the most widespread solution adopted in motorcycles.

3. PROPER MAINTENANCE OF BRAKE ROTORS

Most drivers think that the brake rotors should never have to be replaced, as they are metal parts which are sufficiently hard so as not to require replacement or servicing. Clearly this is not the case and in this section we will attempt to show why the maintenance of the **whole** brake system of a vehicle is fundamental.

Firstly, it should be taken into account that the brake rotors are not infinitely rigid but deform like any vehicle part. In order to prevent this deformation as far as possible many parameters must be taken into account, as even the tightening of the wheels is one of the factors which affect the deformation of the rotor. It is necessary for the tyres to be fitted with the torque recommended by the manufacturer, using a torque wrench set to 0kg/m for steel wheels and around 11kg/m for alloy wheels, carrying out the tightening equidistantly. Pneumatic torque wrenches may deform the system, leading to problems and even breakages in the wheel itself, particularly if it is an alloy wheel.

As a general rule, the proper maintenance of brake rotors requires that they be serviced every 12500 Miles. This check should not just be visual, as there is a minimum level after which the rotor should be replaced. This measurement, known as the MINIMUM THICKNESS, is engraved on the edges of the rotors. We will see what happens when this thickness is not observed later. The checks which must be carried out include not only the measurement of the thickness with the help of an external micrometer, but the warping of the rotor must also be checked with the help of a magnetic base with a dial gauge attached to it. The process of verifying the warping is carried out by fixing the magnetic base to the stub of the vehicle and the end of the dial gauge must be in contact with the brake rotor; once in this position the gauge must be set to zero. Once the whole system has been put in place, the rotor should be turned, taking note of the deviation shown on the gauge. If this variation is greater than 0.125mm the rotor must be replaced as it is warped. This will become obvious in the brake itself as it will cause vibrations in the steering wheel when braking, and if the warping is very serious brake pedal pulsation may even occur.

The flatness of the rotor is a critical element for gradual and vibration-free braking not only when cold but also when hot, when hot judder can occur, causing very unpleasant vibrations when braking. As will be seen later, judder can take the form of acoustic vibrations, structural vibrations in the steering of the vehicle or brake pedal pulsation.

The resolution of these types of problems is complex and obviously entails the installation of the highest quality brake rotors and brake pads with suitable compressibility and friction coefficients.

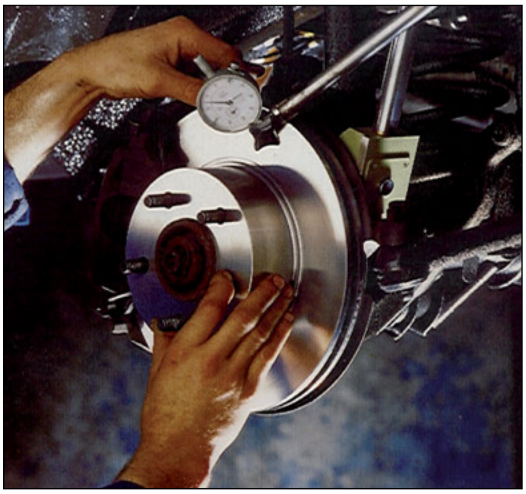
In some cases, rust may also be seen in the brake rotors of the rotors, which has formed as a result of the vehicle being in a very humid environment. This does not imply a serious problem as after braking a few times the rust should be removed by the contact between the pads and the rotor. If once these braking processes have been carried out there is still an area where the rust has not been removed, there may be a problem in the caliper.

If deep circular scratches or numerous radial cracks are observed, the rotors must be changed immediately.

THE ROTORS MUST BE REPLACED IN PAIRS AND THE PADS MUST ALSO BE CHANGED EVEN IF THEIR USEFUL LIFE HAS NOT COME TO AN END.

4. MAIN PROBLEMS ASSOCIATED WITH THE ROTORS

The study of the different problems seen in rotors has shown that most of them could be avoided if more attention were paid to their installation. This not only relates to certain checks which can be quantified by means of measurements, but a visual examination of the components should also be carried out.



Checking the warping of the rotors

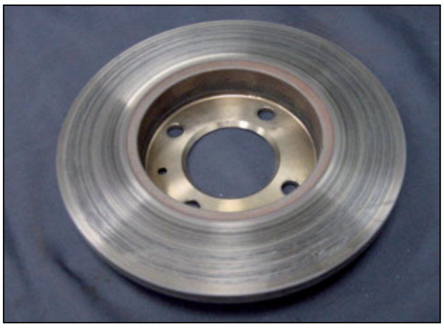
The solution to all the problems described in this chapter is the replacement of both rotors, as well as the pads.

INCORRECT TIGHTENING

DESCRIPTION OF THE PROBLEM:

Excessive tightening of the rotors creates cracks in the surface of the bell which is supported by the bushing. These cracks may not be visible or could initially be deformations which with the passing of time and the continual changes in temperature, in extreme cases, may cause the bell of the brake rotor to become detached. This problem also occurs due to either the tightening order or tightening pressures not being observed.

This deformation will be noticed as soon as the rotor has been fitted and can be detected by vibrations in both the pedal and steering wheel irrespective of the speed, pressure or temperature of the brake system. It is therefore easy to attribute this problem to the incorrect tightening of the rotor or the installation of a defective or badly machined rotor.



Defective rotor due to incorrect fitting of the calliperDefective rotor due to incorrect fitting of the calliper

INCORRECTLY FITTED CALIPER

DESCRIPTION OF THE PROBLEM:

If the caliper has not been correctly fitted in its position we will see uneven wear of the pads in a conical and antisymmetric shape.

The defect can be seen as soon as the rotor has been fitted as very loud noises will be heard when braking, in addition to the banging of the pads and a major decrease in the efficiency of the brake system.

EXCESSIVE PLAY IN THE BUSHING BEARINGS

DESCRIPTION OF THE PROBLEM:

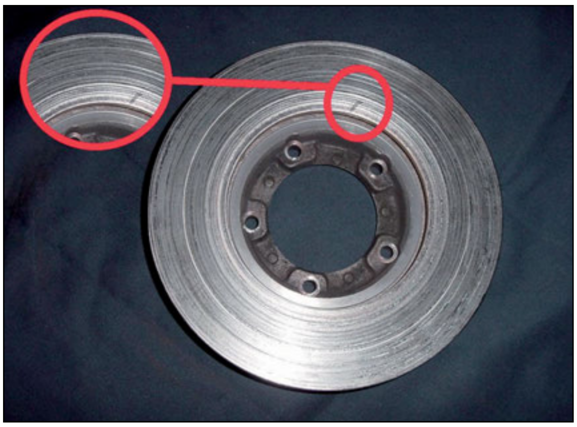
Excessive play in the bushing bearings causes uneven wear of the brake rotors. Overheating of the rotor is seen in the area where the pads rub when the rotor turns, due to the play in the bushing bearings. Excessive wear can also be seen in the area where there is permanent contact.

Frequent vibrations will be noticed from the beginning and will become increasingly serious.

INCORRECT CLEANING OF THE BUSHING

DESCRIPTION OF THE PROBLEM:

When the surface for supporting the rotor in the bushing is not correctly cleaned during the installation of a new rotor, unstable bedding in of the rotor in the bushing may occur, which means that when turning, an oscillation is produced that causes the rotor to rub against the pads on each turn, leading not only to excessive wear of the pads but also to damage to the rotor.



Defective rotor due to play in the bearings

This causes vibrations which will increase as time goes on. Uneven wear will also appear due to the vibrations which are caused in the rotor. In order to prevent this effect it is essential to thoroughly clean the bushing surface. To prevent this problem, always use the indicator to check that the maximum deviations are within those permitted.

EXCESSIVE TEMPERATURE:

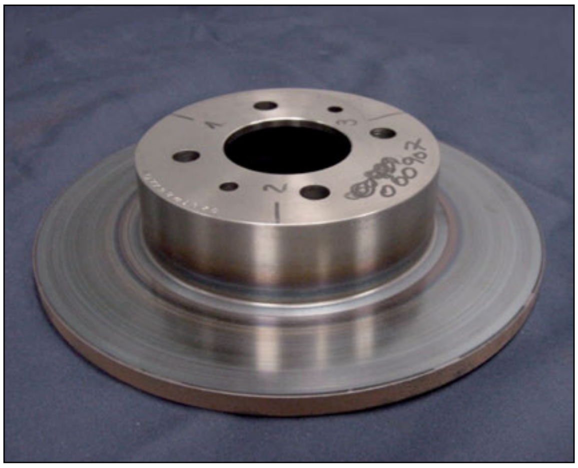
DESCRIPTION OF THE PROBLEM:

The rotors have a range of bright blue colours which are mainly visible in the area of the heat filter which is attached to the bell. This area changes colour as it is suddenly heated up and the structure of the material is transformed.

The increase in temperature causes the structure of the material of the rotors to vary which may even form areas of cementite (Fe_3C), the structure of which is damaging to the brake system as it causes vibrations and changes in the behaviour of the friction material in that area in comparison with the rest, due to it having a different friction coefficient (m). Thermal tensions also accumulate in this area which encourage the appearance and spreading of cracks.

In order for this problem not to appear it is necessary to run in the pads and new rotors for around 120 or 150 Miles, a period during which braking should be gentle and gradual. Excessively heating the rotors should then be avoided during their useful life.

This excessive heating usually has clearly differentiated origins such as driving on the limit or the habit of some drivers of keeping their foot on the pedal during prolonged descents, applying very little pressure, in order to slow down the vehicle.



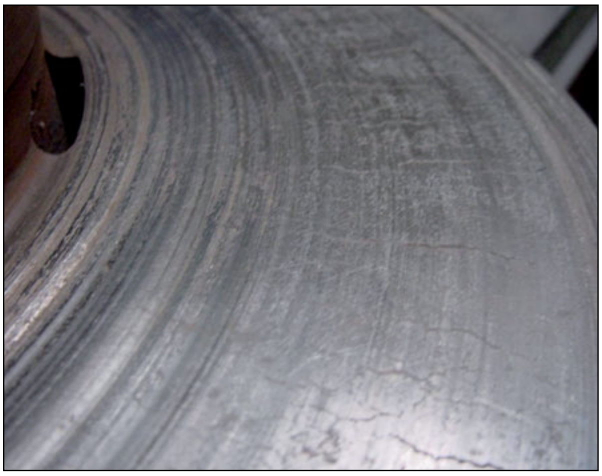
Defective rotor due to being subjected to excessive temperatures

This problem causes vibrations in the rotors due to the structural transformations of the rotor undergone as a result of the excessive temperature. These vibrations will also become increasingly pronounced the higher the mileage covered.

WEAR ABOVE THE MAXIMUM LIMIT

DESCRIPTION OF THE PROBLEM:

When the rotor has been used beyond its useful life; in other words, when the minimum thickness specified by the manufacturer has been exceeded, a notch appears in the rotors which causes a reduction in the mass of the rotor. This leads to poor heat dissipation due to a reduction in the mass of the brake rotor, which will in turn lead to excessive heating, causing the appearance of cracks, as well as patches of a darker colour resulting from the overheating of these areas.



Defective rotor due to an excessive use beyond its maximum limit

It is important to remember that the loss of mass of the rotor causes its thermal conductivity to decrease so that a much greater and faster increase in temperature occurs. This excessive temperature means that the rotors are deformed with the consequent appearance of noise and vibrations.

It is advisable to periodically check the thickness of the rotor, and to replace the rotors every two sets of pads. *It is essential that whenever the rotors are replaced, the pads should also be replaced.*

CRACKED ROTORS

DESCRIPTION OF THE PROBLEM:

The rotors have been subjected to very high working temperatures and symptoms of overheating can clearly be seen in the external part of the rotor. The high temperatures encourage the appearance of cracks, as they make the material more fragile. If there are already small micro-pores, these will therefore develop until a crack is formed.

The cracks occur due to the deformations undergone by the rotors and the impacts that the pads cause on the rotor. Vibrations occur and there is the possibility that one of the cracks could grow to the extent that they cause the rotor to break, with the consequent risk that this entails.

Before reaching the point where the rotor breaks, the frictional characteristics of the pad/rotor unit are radically altered as a consequence of the third layer breaking, with unpredictable results for the vehicle's braking and in any

Defective rotor due to the appearance of cracks *case with signs of premature wear of the brake pads. The picture shows how the premature wear of the pads has made notches in the rotor. The groove left by the base of the pad can clearly be seen on the outside edge of the rotor.*

This type of problem can be recognised by the major vibrations seen in the pedal and steering, as well as the noise caused in any moving situation.

EXCESSIVE WEAR OF THE ROTORS DUE TO TOTAL WEAR OF THE PADS

DESCRIPTION OF THE PROBLEM:

If the pads have been worn so much that that there has been a metal/metal contact between the rotor and the base of the pad, extremely abrasive wear will be seen which leaves very pronounced grooves. Transformation of the material between the rotors can also be seen, as dark areas appear.

This problem can be recognised by a decrease in the efficiency of the brake as well as the noise that occurs when braking with the consequent increase in the temperature that occurs in the metal/metal contact. In order to avoid the problem, the wear of the pads must be verified every 7500 Miles as should the condition of the electrical circuit of the wear warning light to ensure that it does not contain any fault which could lead to an occurrence of the aforementioned problem.

Defective rotor due to total wear of the pads

ROTOR DAMAGED DUE TO THE FRICTION MATERIAL BEING VITRIFIED

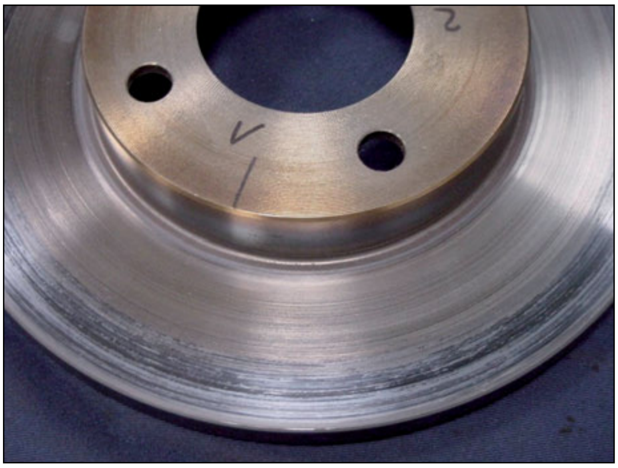
DESCRIPTION OF THE PROBLEM:

This problem is caused by low quality friction materials and vehicles which place high demands on the brakes due to their high performance, such as delivery vehicles, or other extreme conditions imposed by the driver.

The main symptoms of this problem are very long braking processes, as there is a significant loss of braking properties. In addition to the pedal feeling very hard, all brake feeling is lost.

This problem frequently occurs when brake pads are used with a high content of resins to facilitate their production or when non-scorched pads have not been sufficiently cured in the press or furnace. This problem is also normally associated with a high level of squeal.

It is important to stress that the brake pads do not recover after suffering this problem. They must therefore be replaced by new brake pads of proven quality.



Defective rotor due to poor quality of the friction material

GROOVES AND DEEP SCRATCHES

DESCRIPTION OF THE PROBLEM:

The formation of deep scratches or grooves may have been caused by the interposition of different foreign materials between the pad and the rotor. These materials may have been inserted between the pad and the rotor during driving. The problem can also be caused by an accumulation of hard material from the pad if it has had a poor mixing process or by foreign elements introduced during the manufacturing process.

The symptoms which can be detected are the appearance of very unpleasant noises both during the braking process and when not braking. A reduction in braking efficiency will also be noticed due to the reduction in the net contact surface area between the rotor and the pad.

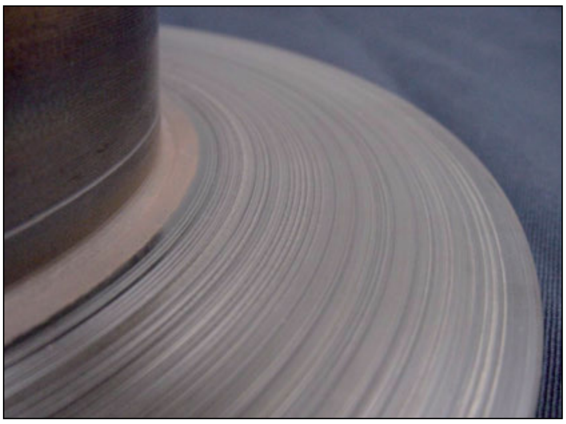
DEPOSITS OF FRICTION MATERIAL ON THE ROTORS

DESCRIPTION OF THE PROBLEM:

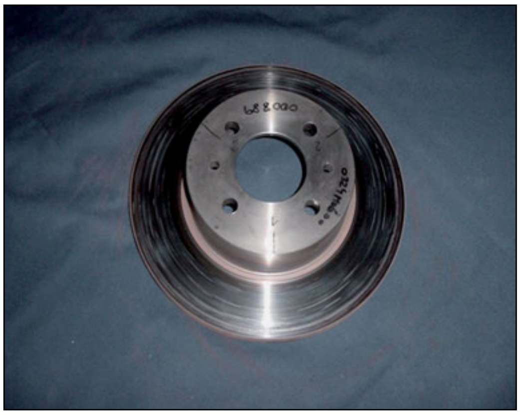
Deposits of the friction material form on the rotor. These have been stuck to the rotor as a result of the high temperature.

Very slight vibrations are noticed initially, according to the braking pressure, but as time goes on the vibrations get bigger and noises appear.

This type of problem is typical of low quality friction material in which from a certain temperature the transfer of the friction material to the rotor occurs with the consequent loss of flatness of the rotor, as well as the modification of the functional characteristics of the pad/rotor unit.



Defective rotors due to the generation of grooves and deep cracks



Defective rotor due to the deposits of material left by the pads

5. SUMMARY

- Periodically inspect the condition of the rotors (every 12000 Miles).
- **Always change the rotors for each axle (pair)** as the friction coefficient (m) corresponding to the brake rotor not only varies slightly from one manufacturer to another, but also changes according to the wear of the rotor**.** A higher friction coefficient (m) in one wheel means that it will not be possible to stop the vehicle in a straight line.
- It is essential to properly **clean** the **housing of the rotor in the bushing**, as if the rotor is not properly fitted into the bushing, deformation of the rotor will usually occur, causing uneven braking which would make the steering wheel vibrate.
- Tighten the fastening screws alternatively and gradually before carrying out the final tightening with the **torque wrench** and according to the torque values recommended by the vehicle manufacturer.
- Thoroughly **clean** the **anti-corrosion oil** of the rotors, as otherwise the remains of this oil could contaminate the friction material, modifying its frictional characteristics.
- **Measure the warping** of the rotors by means of the dial gauge. If the difference between the maximum and minimum value is greater than 0.125mm, dismantle the rotor in order to inspect its housing surface and that of the wheel bushing and reinstall it in a different position to the previous one in order to verify that the warping is within the maximum acceptable value.
- It is essential to **brake gently for the first 150 Miles** in order to properly bed in the pads and the rotors. This bedding in will prolong the life of the rotors and the pads, in addition to improving braking efficiency.
- Periodically inspect the thickness of the rotors on the working surface. If the average thickness is below the minimum thickness specified by the manufacturer, the set of rotors must be replaced. The minimum thickness of the rotor is usually engraved on the edge of the rotor, with the letters MIN-TH-XX (Minimum Thickness XX). The measurement of the minimum thickness also appears in the manufacturer’s catalogue. It is important to replace the rotors when they fall below this measurement as the heating slope is much steeper, causing fading, premature wear in the pads and other types of unwanted problems in the brake system, as a consequence of the temperature increase.
- The rotors should never be machined unless the lathe to be used has the required precision for this purpose, and the intention should be to clean the rotors, not to smooth them down. This means that in order to machine the rotors, a number of considerations should be made, as the minimum thickness recommended by the manufacturer should never be exceeded. Likewise rotors should not be machined on lathes whose precision, bench rigidity, etc. is not that required to leave a good surface finish. It should also be remembered that when the rotors are manufactured, like all rotating vehicle elements, they must be balanced both statically and dynamically in order to ensure that no vibrations are caused to the vehicle. When a rotor is machined, checks are never carried out to see if the rotor is still balanced; it is therefore very likely, particularly if the machining has been very deep, that the rotors will cause vibrations, not only when braking but even when turning the vehicle.
- Always change the pads when the rotors are changed, as maintaining used pads will significantly reduce the life of both the rotors and the pads and will reduce the efficiency of the brake system.

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CHAPTER 6

DIAGNOSIS AND MOST FREQUENT FAILURES IN THE BRAKE SYSTEM

1. INSPECTION OF THE BRAKE SYSTEM

The first thing that we must do before starting to work on the brake system of any vehicle is to carry out a preliminary inspection. This should include a brief chat with the vehicle driver as they are the ones who can best tell us what is wrong with the car and, based on what they tell us, the necessary work can be carried out.

PEDAL TESTS

Press and release the pedal several times (with the engine running for systems with brake booster) and check for friction or noise. The movement of the pedal should be smooth and it should move back into place quickly, without any squeal from the pedal or the brakes.

Firmly press the pedal (with the engine running for systems with brake booster), check that the feel is flexible and calculate the pedal resistance. The feel and play of the pedal should be firm, not spongy.

Check for brake fluid leaks. Maintain slight pressure on the pedal for 15 seconds and check that there is no movement of the pedal. Repeat the test by pressing firmly on the pedal. For systems with brake booster, repeat the whole test with the engine running.

Press lightly on the pedal and release it to check that the brake lights go on and off.

INSPECTION OF THE MASTER CYLINDER AND BRAKE FLUID:

Check that the ventilation holes in the reservoir lid of the master cylinder are open and clean. Confirm that the level of the fluid is near the top part of the reservoir (both sides for double brakes), and that it is clean. Add fluid when necessary.

Tests on the pedal

Check if there are any external fluid leaks. See if there is any dampness around the body, connections and fastening bolt, as well as on the hydraulic brake light switch (where applicable*).*

INSPECTION OF HOSES AND PIPES:

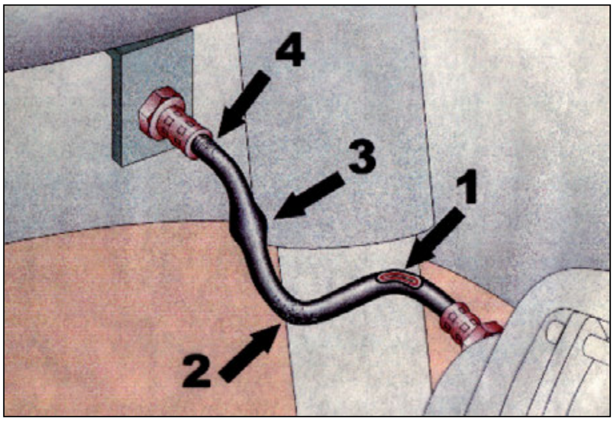
Lifting up the bonnet, check the hoses, pipes and connections and verify that there are no leaks. Check the mounting plates and the wheels to see if there are any signs of fluid or grease leaks.

Check that the pipes do not have any dents or similar damage. Check the condition of the hose (which should be flexible with no cracks, cuts or protuberances).

INSPECTION OF THE WEAR OF THE PADS

Every 7500 Miles, or every time the brakes are checked according to the recommendations of the manufacturer, take off the front right wheel and observe the state of the wear of the pads. If there is only 3mm of usable pad left, the pads must be changed. If you are not sure, remove the other wheels and examine the pads.

If there is a wear warning system in the pads check all the wiring to ensure that it continues to fulfil its function.



Inspection of the brake hoses

INSPECTION OF THE BRAKE MECHANISMS:

Check the pads and ensure that the friction material is properly fixed to the base. Also look to see if there are cracks, abnormal wear or any encrusted foreign particles.

Check if there are cracks or if the material is deformed. Confirm that the parts for mounting the pads (bolts, springs, cramps, etc.) are correctly installed and are not damaged.

2. MOST COMMON FAULTS AND POSSIBLE SOLUTIONS

Shown below is a summary of the most frequent faults, their possible causes and the most advisable solution. However, it should be pointed out that some of the faults described here might have occurred for different reasons, and there may well be more appropriate solutions than those analysed below. In short, this section should be used merely as a guide for the possible location and solution of faults.

3. ANALYSIS OF SPECIFIC PROBLEMS

EXCESSIVE PEDAL PLAY	
PROBABLE CAUSES	**SOLUTIONS**
1.-Leaks in the circuit.	1. Check the whole circuit and replace the damaged part.
2.-Air in the system.	2. Bleed the system and refill it.
3.-Inappropriate or contaminated brake fluid.	3. Wash the system with methyl alcohol and then fill it with the appropriate fluid.
4.-Low level of brake fluid.	4. Fill the reservoir with brake fluid and bleed the system.
5.-Very worn pads.	5. Replace the pads

SPONGY PEDAL	
PROBABLE CAUSES	**SOLUTIONS**
1. Air in the hydraulic system.	1. Remove the air by bleeding the system.
2. Fluid which is inappropriate or contaminated with water.	2. Wash with methyl alcohol and use the appropriate fluid.
3. The caliper piston is stiff.	3. Clean the piston housing and replace the retainer and the dust cover.
4. Weakened hose.	4. Install new hoses.
5. Seized caliper	5. Replace the caliper.

THE PEDAL HAS TO BE PRESSED VERY HARD IN ORDER TO BRAKE	
PROBABLE CAUSES	**SOLUTIONS**
1. The pads are impregnated with grease or brake fluid.	1. Check where the loss is occurring and replace the pads.
2. Movement of the seized caliper.	2. Clean the piston chamber and replace the retainer and dust cover.
3. Inappropriate or small amount of fluid.	3. Wash the system with methyl alcohol, fill it with the appropriate fluid and bleed it.
4. Master or wheel cylinder stuck.	4. Check all the hydraulic elements and replace the stiff parts.
5. The brake pedal is obstructed on its axle.	5. Lubricate it and check the fitting.
6. Crystallised pads.	6. Install new pads.
7. Damaged rotors.	7. Replace the rotors.
8. Malfunctioning of the brake booster.	8. Confirm that it works and repair the damaged parts.

DECREASING PEDAL PLAY	
PROBABLE CAUSES	**SOLUTIONS**
1. Master cylinder rubber punctured. 2. The main cylinder piston does not return to its position. 3. Weak retractor springs. 4. Caliper piston stuck.	1. Replace retainers and dust covers and wash the system. Fill it with new fluid. 2. Repair the main cylinder or replace it. 3. Replace the springs. 4. Clean the piston chamber, lubricate and change the retainer.

ONE WHEEL LOCKS	
PROBABLE CAUSES	**SOLUTIONS**
1. Loose wheel bearings. 2. The rubber of the wheel cylinders or the caliper piston retainer has swollen. 3. The pistons in the wheel cylinder have seized. 4. Obstruction of a pipe. 5. Defective pad. 6.-The handbrake cable gets stuck.	1. Adjust or replace the bearings. 2. Rebuild the cylinders/caliper. Use new repair sets. 3. Replace the pistons. 4. Replace the obstructed pipe. 5. Replace it with the specified pad. 6. Lubricate it and confirm that the system works correctly.

BRAKE PEDAL PULSATIONS	
PROBABLE CAUSES	**SOLUTIONS**
1. Warped rotors. 2. Wheel bearings worn or loose. 3. Vibrations in the pedal (JUDDER)	1. Change the rotors. 2. Replace them. 3. Replace the pads and the rotors, as this problem cannot be corrected in any other way.

THE BRAKES VIBRATE	
PROBABLE CAUSES	**SOLUTIONS**
1. Pads with grease, fluid or dust. 2. Return spring broken or weakened. 3. Wheel bearings loose. 4. Warped rotors. 5. Unbalanced wheels. 6. Ball and socket joints in bad condition.	1. Replace the pads of the whole axle. 2. Replace it. 3. Readjust or replace them. 4. Change the rotors (always on each axle). 5. Balance the wheels. 6. Replace them.

THE CAR SWINGS TO ONE SIDE	
PROBABLE CAUSES	**SOLUTIONS**
1. Pads on one side impregnated with greases or liquid. 2. The tyres do not have the appropriate pressure or have uneven wear or different tread design. 3. Crystallised pads. 4. Wheel cylinder blocked. 5. Return springs loose or weakened. 6. One wheel drags. 7. Looseness in steering. 8. Steering levels. 9. Hydraulic pipes covered or bent. 10. Looseness in steering ball and socket joint. 11. Rotors in bad condition. 12.-Shock absorbers in bad condition.	1. Change the pads of the whole axle. Check for possible fluid losses. 2. Inflate the tyres to the recommended pressure. Place tyres of the same model on the front axle and another pair with the same design on the rear axle. 3. Replace the pads. 4. Change the wheel cylinder. 5. Check the springs and replace them. 6. Check to see if there is a loose pad and investigate the cause. 7. Repair and adjust the steering. 8. Align the steering. 9. Repair or replace the pipes. 10. Replace the steering ball and socket joint. 11. Replace them. 12. Replace them.

THE BRAKES LOSE EFFICIENCY WHEN HOT	
PROBABLE CAUSES	**SOLUTIONS**
1. Low quality pads. 2.- The pad makes poor contact. 3. Very thin rotor.	1. Replace them with pads of proven quality. 2. Check the cause and fit new pads. 3. Replace the rotors.

THE BRAKES SQUEAL	
PROBABLE CAUSES	**SOLUTIONS**
1. Anti-noise shim bent, broken or out of position. 2. Metallic particles or dust encrusted in the pads. 3. Low quality pads. 4. The pads rub against the caliper. 5. Mounting springs weak or broken. 6. Wheel bearings loose. 7. The caliper piston does not return correctly. 8. Rotors in bad condition. 9. Extremely worn pads*****.	1. Replace the pads on the whole axle. 2. Replace the pads on the whole axle. 3. Replace them with pads of proven quality. 4. Apply lubricant to the supports between the pads and the caliper. 5. Replace the defective parts. 6. Check and replace them if necessary. 7. Repair the caliper. 8. Replace the rotors on the whole axle. 9. Install new pads of proven quality.

* Although the compressibility of a friction material depends on its own composition and structure, this compressibility is completely proportional to the thickness of the brake pad. Although the relative compressibility is maintained, the total compressibility therefore decreases with the life (thickness) of the pad and can frequently be situated in a critical area for causing squeal. The installation of new pads usually solves this problem.

FADING

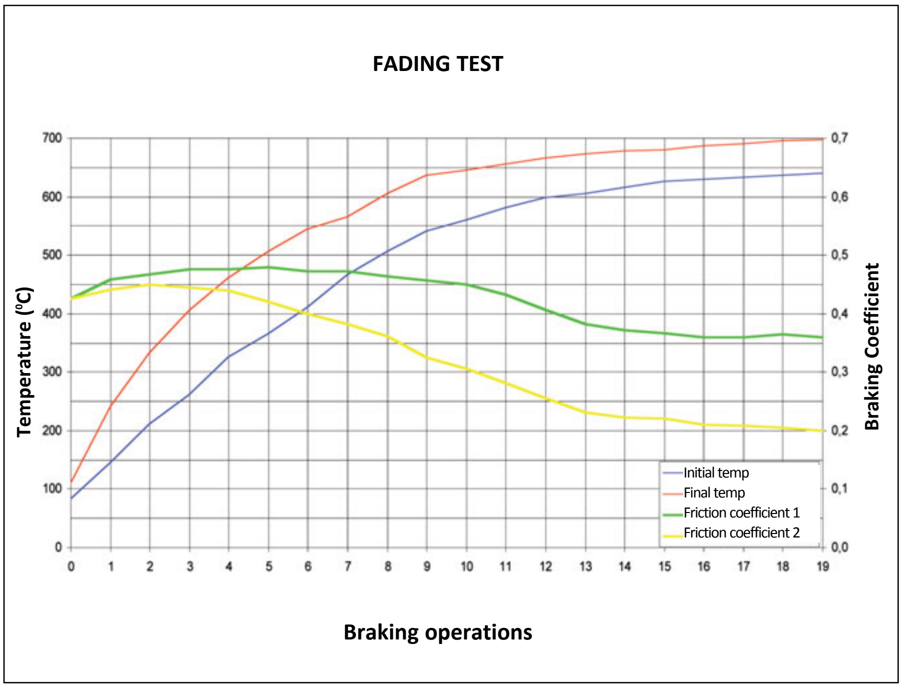
Fading is one of the most dangerous phenomena which can occur in a brake system, as it involves the loss of efficiency under hot braking.

Friction material has different coefficient values at different temperatures. If this friction coefficient begins to fall too quickly and at a relatively low temperature, the fading phenomenon will occur when the temperature of the system is above the limit of the friction material; the coefficient will therefore drop and the braking efficiency will be reduced. The graphs below show how fading occurs.

In the graph we can see the comparison of two different friction materials, in what is known as a fading test. The fading test is carried out in an inertia dynamometer; a machine which is able to simulate the conditions imposed on a vehicle, with the particular characteristic that its set of sensors are capable of measuring all the parameters of braking processes.

The fading test is made up of 20 consecutive braking processes in which both the braking start temperature and the final temperature reached are measured, in addition to the friction coefficient which measures the capacity of the friction material to stop the vehicle. All the braking processes are carried out from 100km/h to 0km/h, and the parameter which must always be fulfilled is that the average deceleration obtained should always be $4m/s^2$. The pressures applied in the circuit are therefore those which achieve the aforementioned average deceleration.

The graph shows how material 1 has a fairly good performance in relation to the temperature, as although its coefficient falls as the temperature increases it always remains at values which we can consider to be acceptable



Comparison of two materials in a fading test

for a friction material. We can also see that when the temperature is 640ºC it still remains at a value of $\mu = 0.46$. If we consider that 640ºC is a very high temperature for normal driving, in other words, under normal driving circumstances when descending a mountain pass, our brakes may reach that temperature even if we do not abuse them. From this point, its descent is more pronounced but the coefficient always remains above $\mu = 0.35$, which allows control of the vehicle to be maintained. Fading coefficients lower than m = 0.25 may be dangerous in certain circumstances.

However, it can be seen that material 2 will have fading problems as at the same point described above its coefficient is lower, reaching a value of μ = 0.33. From this point it keeps falling until a value of μ = 0.20 is reached and it can clearly be seen that there is a considerable loss of efficiency.

Fading is easy to see in the vehicle as when we attempt to brake we notice that the pedal has to go increasingly closer to the floor in order to obtain the same deceleration and therefore greater pressure has to be applied to the brake pedal. In this situation the braking feeling is reduced. We attempt to stop the vehicle but it will not slow down. The increase in pedal play is due not only to the compressibility of the pads, if this compressibility is too high when hot, but also to the fall in the friction coefficient resulting from the effect of the temperature.

It is important to be aware that once fading has been suffered, if the system is allowed to cool down, the friction material will partly recover its performance again, almost reaching the level prior to the problem occurring. Logically if we again subject the material to extreme conditions the fault may occur again. In these situations, it is advisable to establish whether the fading that has appeared is of an initial nature, in other words, it is due to the pad running in phase, in which case this problem will disappear with use, or whether it is of a structural nature, in which case it will never disappear during the life of the brake pads in use. In the latter case it will be necessary to replace the brake pads with others of a proven quality brand.

A distinction should be made between the problem of fading and the problems caused when the brake circuit contains water, which have virtually the same symptoms. Extremely worn brake rotors can also cause an abnormal increase in the temperature which places the friction material in a fading situation.

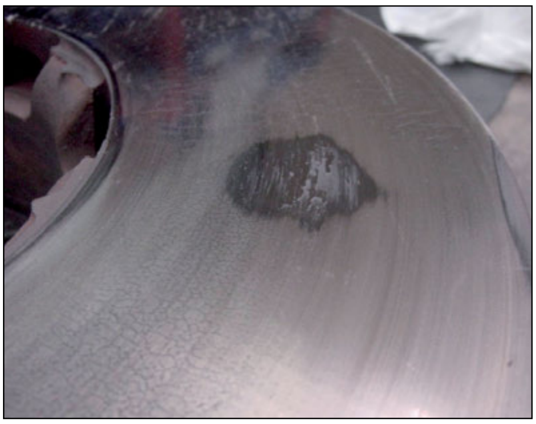
JUDDER

Judder is a phenomenon associated with vibrations of the system, in other words, vibrations which will be more or less palpable to drivers, depending to a large extent on their knowledge of the vehicle. Judder may be accompanied by noise, although always of a low frequency; we should remember that the noise is caused by vibrations which reach audible frequencies.

Judder is classified into two groups:

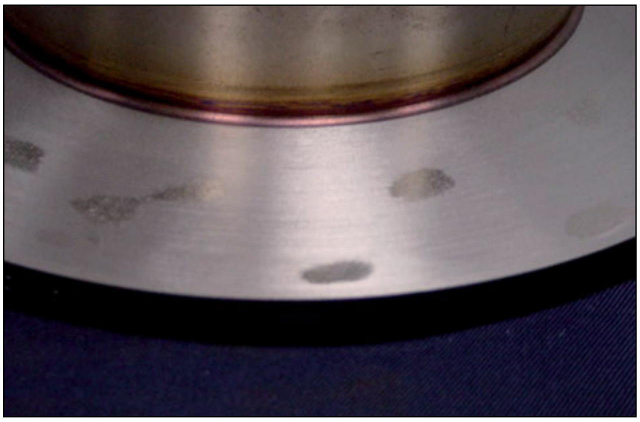
The first is cold judder. These vibrations are caused by faults in the rotors such as factory-originated machining defects, as well as installation defects or excessive looseness; in other words, all the causes which lead to an increase in the deformation of the rotor. This **cold judder** is usually caused at low pressure and low deceleration. When the pads pass over these imperfections they cause the vibrations as they are knocked against the piston. It may be noticed in the pedal and the steering wheel if the judder is very pronounced, in the form of vibrations, noises or both. Obviously the quality of the brake pads can also increase or reduce the problem.

The second group is hot judder, which consists of vibrations which appear at high temperatures during braking

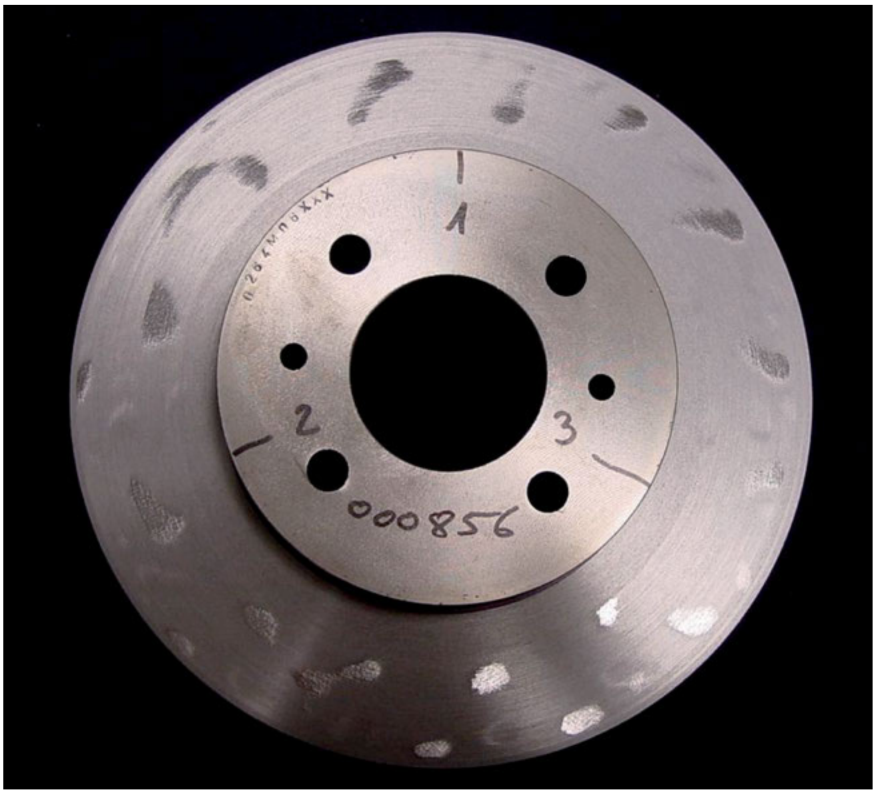


Cold judder patch

processes at medium pressures and high speeds, as braking processes in these conditions are prolonged over time and the temperature increases considerably, reaching values of 400ºC to 500ºC. **Hot judder** occurs when the friction between the pads and the rotors is higher in a particular area of the rotor. In this area, the energy dissipated will be greater and the temperature will therefore be higher, increasing rapidly. The vibrations appear in the hot points, which are usually evenly distributed throughout the area of the rotor. When these hot points cool down, they create dark patches or areas of a different colour which are very hard and may be more or less visible. These patches are the result of the transformation of the structure of the rotor material. The structure changes from being made up of flake graphite to cementite. This structure is characterised by its extreme hardness. This change in structure is usually caused by the friction material itself, which has an area where the coefficient varies, which may be due to encrustations of badly mixed raw materials or simple variations in the coefficient due to the effect of the temperature in the different areas of the brake pad.



Hot judder patches.



Transformation of the rotor material. The rotor in the picture has been machined and even so the patches caused by the hot judder have not been removed.

The structure of the rotor material which has been transformed has changed to cementite (Fe_3C), a structure characterised by its extreme hardness. This means that if braking is continued in these circumstances, these areas will wear less, contributing to an increase in the vibrations. The machining of the rotors will not solve this problem. The effect of **hot judder** is thus one of the most widely studied defects, with attempts being made to eliminate it through the investigation of new friction material properties which provide an adequate hot compressibility ratio and thermal conductivity in order to avoid as far as possible this problem, which has become more widespread in the latest generations of vehicles with lighter non-suspended masses. In other words, the wheels, suspension, brake calipers, etc. are increasingly being manufactured in lighter materials such as aluminium which reduce the weight of the unit and make its agitation easier.

NOISE

The noises which occur in the brake system are the result of the vibrations to which the pads, rotors, pad carriers, calipers, etc. are subjected due to the mere fact of being subjected to a friction. Although the pads and the rotor may appear to be in *perfect* contact during braking, this is not the case as the pads, like the rest of the system, are being subjected to constant little knocks which cause the vibrations. We should remember that any material will tend to vibrate when subjected to percussion, in a characteristic manner; in other words, its form of vibration will depend on its mass, density, elasticity module, etc.

The noises occur when this vibration coincides with a frequency typical of any element of which the system is comprised, be it the pad carrier, caliper, stub, etc. This means that although the noises are caused by the friction between rotor and pads, these are merely the exciters of the system.

It should be remembered that for a noise to occur we need the following 3 fundamental elements: an exciter, a resonator and a propagator. When any of us speaks, the exciter is our vocal chords, which vibrate causing waves in the air, which is the propagator, and our larynx is the resonator. In the case of the brake system, the exciter is the pads that cause the vibrations in the rotor, which is usually the resonator and the only thing that does not vary is the propagator, which is still the air.

Noise is one of the biggest problems of the brake system as it can be unpredictable. In many cases what happens is that the noise occurs in a particular series of vehicle chassis numbers, but does not occur with the same material in the next series. It is possible that small changes in driving habits, load conditions or environmental conditions may lead to the appearance of squeal.

How can the noise be prevented from occurring? The initial developments of the formulations are aimed at ensuring that noise and other undesirable effects do not occur. However, the range of factors that lead to this effect taking place require other types of measures to be taken, as even if the material does not initially cause noise, it may be that the condition of the rotors, suspensions, ball and socket joints, etc. cause it to appear. In order to avoid this, the manufacturers have introduced anti-noise shims, elements which prevent the vibrations from spreading through the pad carrier. In many cases these elements carry out their function, but are not sufficient as the randomness of the event means that even with these preventative elements the problem continues to be seen in some cases. On other occasions, attempts are made to modify the behaviour of the pad in response to the vibrations by changing the contact surface with the rotor; in other words, channels, slots or chamfers are introduced which, in addition to being used for the elimination of particles and for refrigeration, also ensure that the type of vibration is varied so that it is possible to prevent the noise from appearing.

The amplitude of a sound should be measured as a variation of pressure in the air, but the human ear has an almost logarithmic response. It is for this reason that units of pressure known as decibels were created, representing variations of air pressure on a logarithmic scale. The human ear can perceive from 30dB to 140dB, with the pain threshold beginning at 120dB.

The fact that the physiological response of the human ear is logarithmic means that noise dampers of approximately 50% at the mechanical level, on a reference level of 100dB, only represent a fall in the perception of noise of 3dB, or 3%. This example clearly illustrates how difficult noise attenuation is not only in the specific field of braking but in any other area where it is intended to attenuate noise.

DECIBELS	POWER NECESSARY	Reference level
90 dB	1 W	
93 dB	2 W	
96 dB	4 W	
99 dB	5 W	
102 dB	16 W	
105 dB	32 W	
108 dB	64 W	
111 dB	128 W	
114 dB	256 W	

In the table above it can be seen that in order to increase the physiological sensation of the acoustic level, for example from 102dB to 108dB, which entails an increase in the acoustic sensation of only 5% (6dB), the power must be increased from 16W to 64W; in other words, a 200% increase in power (48W).

If there is a need to reduce the acoustic sensation; in other words, if what we need is to absorb the noise, the behaviour is exactly the same as that described to cause it to increase. Hence the difficulty of noise attenuation, whether it is of a general type or specifically relates to the brake system.

The reason for this behaviour lies in the fact that its response is logarithmic and significant variations in pressure (SPL) therefore result in small variations in the acoustic sensation.

Described below are the different types of noise which can occur in a brake system.

- ❑ GROAN: occurs at low frequency, when the vehicle is moving at low/medium speed and the brakes are actuated with low pressure. It is a type of low noise which is very easy to detect in entrances to garages and in slow traffic situations. It is usually a noise which is not detected by users and is very common in vehicles equipped with an automatic gearbox.
- ❑ JUDDER: as we have seen in the chapter on vibrations, judder is a vibration which can turn into an audible noise. Like groan it is a low type of noise which is not usually detected by the user unless it is a very serious judder which causes vibrations in the steering wheel, brake pedal or chassis.
- ❑ SQUEAL: this type of noise is more widely known by all vehicle users. It occurs when the vibration frequency of the pad against the rotor is sufficiently high. It is a very piercing noise which is very unpleasant for the human ear. There is a kind of squeal known as high-frequency squeal which occurs at a higher frequency and is a very piercing noise at high decibels, around 100dB(A), which is extremely unpleasant for the driver.

All the research into noise starts from an empirical basis which links the compressibility, hardness, and friction coefficient of a particular friction material. However, after an initial approach of a theoretical nature extensive laboratory work on the brake pad is necessary in order to optimise its performance in the noise test bank prior to the tests carried out on the vehicle itself.

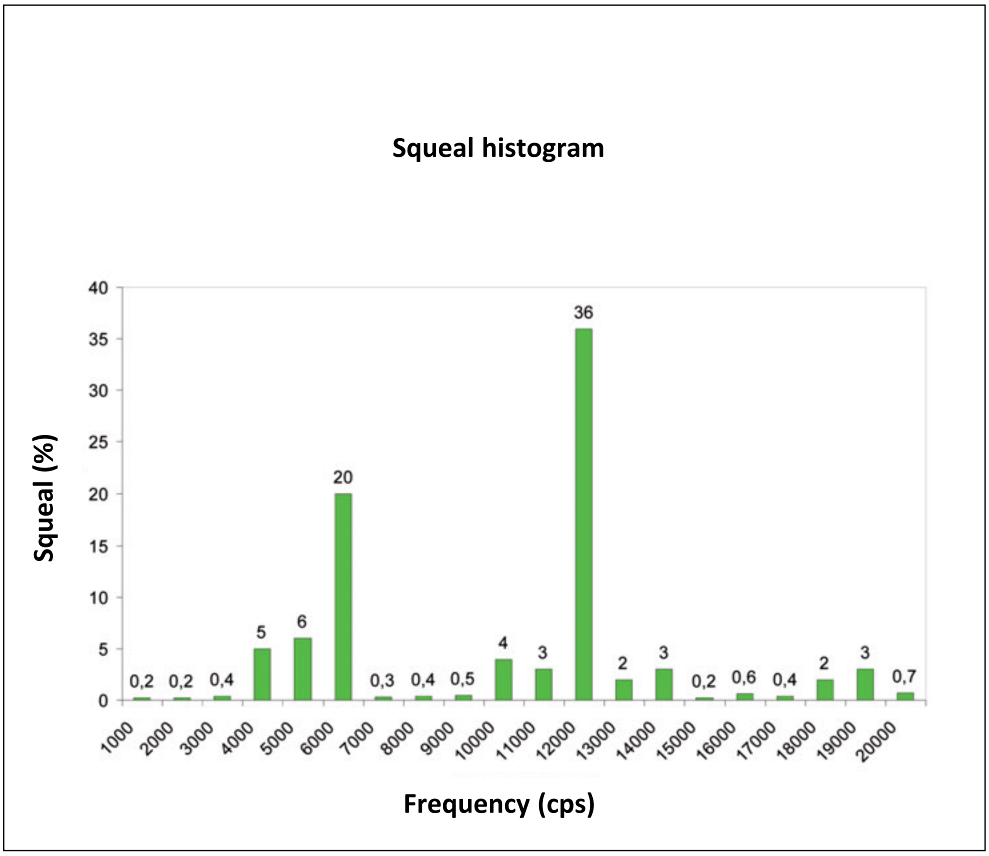
The typical tests to be carried out on various samples of the same friction material consist of around 3000 braking processes per set, going forwards and in reverse gear, at variable pressures, speeds and temperatures. The diagram on the next page shows a histogram taken from a wheel test stand, in which the frequency at what the noise occurs and the percentage of times that the noise has occurred at that frequency can be seen.

Obviously these tests are very slow and therefore costly. However, they enable the friction material to be optimised in order that the testing on the vehicle itself may be significantly reduced.

There are however types of vehicles or brake systems in which optimisation is only partially possible and it is therefore necessary to resort to the installation of anti-noise shims in the brake pad. This not only improves this problem but also reduces the transfer of heat to the caliper and the hydraulic circuit. In fact, a large majority of state-of-the-art vehicles incorporate these anti-noise shims as the only possible way of guaranteeing the resolution or at least improvement of this problem.

It can be seen that the friction material subjected to noise testing in this case has two frequencies, 6000cps and 12000cps, at which the percentages for the occurrence of squeal peak at 20% and 36%, respectively, whilst in other areas of the acoustic spectrum, the percentages are much lower or even non-existent.

The chart below shows the increase in the power required to listen to a sound at a certain number of decibels at a distance of one metre if the wave has a frequency of 1000 cycles per second. On the basis of a standard speaker which, with 1W of power, enables us to listen to the music at 90dB when we are situated 1m from the speaker, the following table is obtained.



PREMATURE WEAR

The problem of premature wear is closely linked to problems of overheating and high temperature in the brake system and also to the use of low quality brake pads. In most cases the brakes are excessively abused and work for a long time at temperatures of over 450ºC. This causes the friction material to stick to the rotor, in cases of low quality brake pads, leading to uneven wear. Cracks begin to appear in the friction material which over time may indicate the beginning of a loss of material mass. Another of the causes which can cause premature wear of the pads occurs during the manufacturing process when the distribution of the mix, during the pressing process, has not reached the required level of homogenisation.

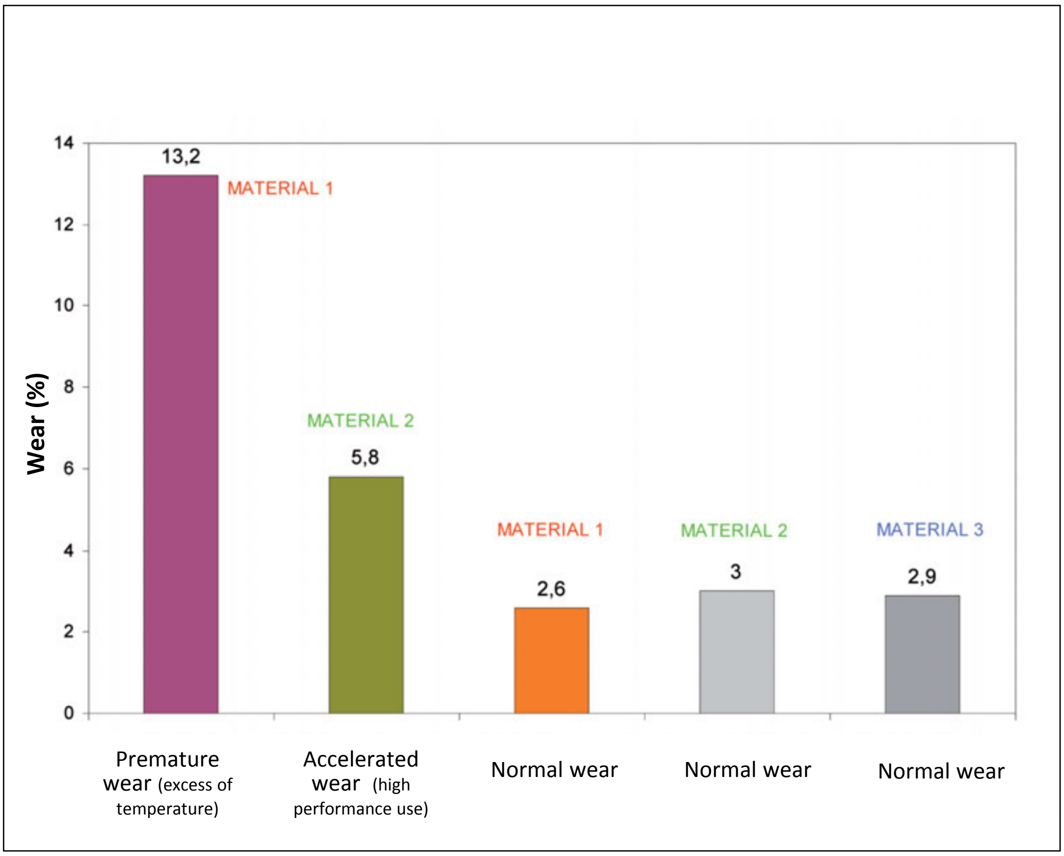
In the area of premature wear, and leaving aside brake pads of insufficient quality, the key is for the caliper to work correctly, as residual pressures (after the circuit pressure has been released) above those required to maintain contact between the pad and the rotor (residual torque) will lead to the system gradually heating up with the consequent effects of an increase in wear as the temperature rises.

Given the importance of the phenomenon described, it is essential to check this residual torque by turning the wheel freely and checking to ensure that there is no rolling resistance. Otherwise a complete service of the caliper should be carried out.

Premature wear may also appear in vehicles whose driver has the habit of driving with their foot on the brake pedal over long descents, even if a low amount of pressure is applied, with the intention of slowing down the vehicle.

The graph above compares the average wear values of different materials. The wear is shown as a percentage for the same number of kilometres covered, with the same vehicle and different materials. The life of a friction material is a very relative value, as it largely depends on the condition of the system, as well as the type of driving undertaken.

As can be seen, according to the figures in the table, wear which is due to the effect of the temperature may lead to reductions in the useful life of the brake pads of over 300 %. Whilst for a normal user this effect has only a slight impact, for certain professional vehicles or drivers it would be advisable to install only high quality elements.



In the graph above it can be seen that for the same material (material 1), according to the type of driving, the wear is different. In the first case, the material was tested in a delivery van which followed a route on which it had to deal with hilly terrain with a lot of mountain passes, and the driver also excessively abused the brake. In the second test with material 1, the same van was used and the same route followed, but with a driver who slowed down the vehicle with the engine and who also drove at a considerably lower speed. In the second case with material 2, under high performance driving conditions, in other words, braking late so that the pressure in the circuit is very high whenever the brakes are used, in order to achieve very high decelerations, the working temperature is very high and hence there is a loss of material. However, with the same vehicle driven normally, the wear percentage of the pads is lower, with differences in wear of approximately 100%. In the third material, the behaviour of the driver is normal and the wear therefore falls within acceptable values.

PULLING

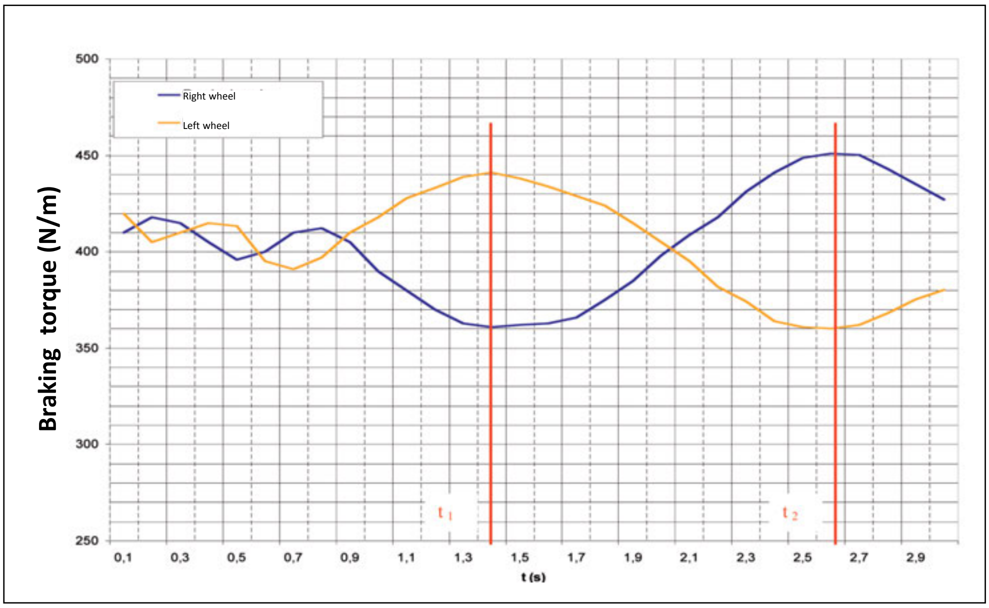
The pulling effect indicates the phenomenon of the car swinging during medium/heavy braking or deceleration to one side and then the other. This phenomenon is not due to a fault in the brake system but the poor performance of the friction material.

The swinging of the vehicle is due to the fact that the braking torques of the pads are not constant during the revolution of a wheel but vary due to the poor development of the friction material.

As this effect is obviously not synchronised in both wheels, a different braking effect occurs in each wheel which produces lateral forces on the vehicle which obviously modify its trajectory moving it away from the straight line in the form of an undulation.

The graph below shows how the braking torques of the wheels vary. It can be seen that at the beginning of the braking process there is a transitory area until good contact between the rotor and the brake is achieved and the pressure reaches a constant value. Once "balance" has been achieved we see that the torques of both wheels are different; in other words, at t_1 the braking torque of the right wheel is 360N/m, whilst the torque in the left wheel is 440N/m. The vehicle will therefore have a directional instability which will cause it to veer to the left. It can be seen in the graph that this continues to vary as the braking process goes on and we see that at t_2, the braking torque of the left wheel has dropped to a value of 360N/m, whilst in the right wheel the braking torque has increased to a value of 450N/m, meaning that the vehicle will veer to the right. This undesirable effect is known as PULLING.

It should be understood that the friction coefficient m even varies during a turn of a wheel and cannot normally be synchronised with the variations in the coefficient m of the other wheel, thus giving rise to the problem shown in the previous diagram.



CRYSTALLISED PADS

The crystallisation of the pad surface occurs during braking processes at high temperatures (450ºC – 700ºC), for example during descents from mountain passes or during very high performance driving with high decelerations. This problem is seen mainly in brake pads with an excess of resin and old manufacturing technology.

What is wrong with the pads? When the friction material in contact with the rotors is hot, at temperatures of over 350ºC, the organic contents of the compound burn, firstly reaching a liquid state, until complete carbonisation occurs and gases and smoke are generated.

During this transformation process a very fine and shiny superficial film can form on the surface of the pad, which causes the coefficient to decrease. This means that the performance of the friction material is lower and the pedal play becomes longer as the friction coefficient decreases as a consequence of this film.

If the friction material is well designed, once the pads cool down, in approximately 50 or 100 braking processes it will recover its initial level of performance. In other words, once the crystallised layer has been “cleaned” from the surface of the pads, performance will be similar to the initial level.

In badly designed materials, when the friction coefficient falls to levels of approximately μ=0.10, the level of performance will not be recovered. This will be noticed as the pedal will be very stiff, with a sensation of a lack of braking even if we push the pedal firmly. When the pads are removed the film with a crystallised appearance will be seen on the surface. This problem is usually accompanied by a significant level of squeal.

The friction material in these conditions is completely irrecoverable and it is therefore essential to change the brake pads.

CHAPTER 7

REGULATION 90:
CURRENT LEGISLATION

1. INTRODUCTION

Replacement brake pad manufacturers are currently required to comply with a regulation that requires them to maintain certain standards of performance. This European regulation has been applicable in European Union since 31 March 2001 and requires all brake pads sold in the replacement parts market to achieve a quality standard, which is described below.

2. REGULATION 90

R-90 approved brake pad

The growth of the free market for car components and the proliferation of brands in the braking sector have led to the need for the European administration to introduce a regulation governing the quality standards for certain safety parts. This regulation defines the characteristics of the braking product itself, irrespective of the other quality standards that companies may have in relation to the manufacturing process and the evaluation of their management systems, such as the ISO9000 or QS9000 standards.

Brake pads are now the focus of a lot of attention as the European legislative bodies have produced guidelines which strictly define the safety and efficiency criteria to be fulfilled by this important car safety component.

One of the most significant aspects of the ECE R-90 regulation relates to the performance of the pads, setting the quality standard level at a tolerance which may not be lower or higher than 15% as regards their speed sensitivity.

The ECE R-90 forms part of Directive 98/12/EC and has been effective for all the member states of the European Economic Community since 11 October 1999. However, a transition period was granted until 31 March 2001.

From this date, any pads that do not comply with the requirements of the regulation may not be sold in the European Union market.

The controls and tests must be carried out by approval bodies which have been officially authorised by each European Union state. Any product which it is intended to sell from the date of entry into force of the regulation must also pass its own quality standard process if this is required for the product in question. This means not only approving one friction material but individually approving each and every one of the products that it is intended to sell, when this quality standard is applicable.

Regulation ECE R-90 is a major step forward in the search for a better product and the best service for the consumer. It defines quality standards which must be adhered to by manufacturers in order to operate in the independent market and represents a guarantee of reliability in the safety products marketed by companies.

It is at last a guarantee for end consumers, who may at any time demand the official approval of the product, and proceed accordingly if the product which has been installed in their vehicle is not R-90 approved.

From 31 March 2001, selling, installing or driving with a non-approved pad, in vehicles for which it is required, shall be considered illegal and its owner shall be liable for the civil and criminal consequences imposed by legislation.

Check if there are any external fluid leaks. See if there is any dampness around the body, connections and fastening bolt, as well as on the hydraulic brake light switch (where applicable*).*

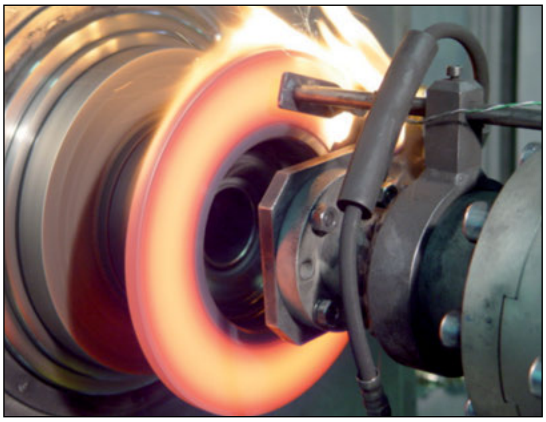
Tests on vehicles

3. ECE R-90 QUALITY STANDARDS

In order for a brake pad product to be Regulation 90 approved, tests must be carried out both in the laboratory and on the vehicle itself. Each pad product must be approved in the vehicle in which it is to be fitted, with the vehicle equipped with sensors. In other words, we need to know the temperature the brakes are at, the pressure being applied in the circuit, the force at which the pedal is being pressed and the deceleration undergone by the vehicle under braking.

ROAD TESTS

- *A series of type 0 approval tests:*
  A sequence of braking processes under different speed and load conditions. The aim is to verify that the brakes work correctly in different service conditions, as well as in emergency and parking conditions. This test is a repetition of the tests carried out by the vehicle manufacturer for the approval of the vehicle under Regulation 13 (relating to quality standards for brakes).
- *Efficiency loss when hot test:*
  Firstly a sequence of 15 braking processes are carried out at high speed in order to place the brake in extreme temperature conditions. Subsequently, it is verified that the brake works correctly, comparing it with the results when cold. The results obtained should not be below 80% of the decelerations obtained in the cold performance test.



Test stand

- *Cold performance equivalence test:*
  With the vehicle fully loaded, at an initial temperature equal to or less than 100ºC and a speed of 80km/h, a series of consecutive braking processes are carried out with different pressures in the front and rear axles, until lock pressure is reached. The idea is to verify that the performance of the spare brake is around ± 15% of the performance of the original equipment, which has previously been tested in the same vehicle.

Inertia dynamometer

- *Speed sensitivity test:*
  The speed sensitivity test is perhaps one of the most important and difficult to pass of the R-90 quality standards. It involves carrying out 3 braking processes at 65km/h, 3 braking processes at 90km/h and 3 braking processes at 135km/h, with the pressure in the circuit identified in the cold performance test, which provides a deceleration of 5m/s2. Calculating the average of the decelerations of these 3 braking processes, a value close to 5m/s2 must be obtained. However, the problem is that the braking processes are significantly prolonged as the circuit pressure must remain constant, which causes the instantaneous temperature in the contact of the pads with the rotor to increase. The effect of the speed means that the deceleration achieved will be much lower, and this product will not therefore achieve the quality standard. It is a test that attempts to keep the decelerations that the friction material is capable of applying to the vehicle completely independent from the vehicle's speed. In other words, the vehicle should brake at both 180km/h and at 40km/h within the limits imposed by this test.

The final approval of the product requires the difference between the average deceleration obtained at 135km/h, 65km/h and 45km/h to be no more than ± 15%.

LABORATORY TESTS

The aim of these types of tests is for the mechanical characteristics of the material to be within certain predetermined values, in relation to the compressibility of the friction material (pedal play) and its mechanical resistance characteristics.

- *Compressibility test:*
  A compressibility machine is used to verify the compressibility of the pad when hot and cold. The compressibility of the pad is an important characteristic of the friction material as the material must be compressible in order to properly adapt to the rotor. In other words, this compressibility means that it is able to absorb vibrations.
  However, very high compressibility when hot can lead to major displacement of the brake fluid, which could result in there being no pedal play and the consequent loss of control of the vehicle as it is left without any brakes.
  The compressibility limits according to the R-90 are 2% of the thickness of the pad for compressibility when cold and 5% of the thickness of the pad when hot.

Compressibility machine

- *Shear stress resistance:*
  Using a shear stress machine, the resistance of the friction material when detached from the metal base is measured by means of a tangential force to both surfaces. This value is very important as it should be remembered that the friction material will be subjected to shear stress forces whilst it rubs against the rotor.

The minimum acceptable values for 100% adherence of the friction material on the metal base are 25kg/cm2, equivalent to 1500kg of resistance for a brake pad in an average type vehicle.

Obviously the requirements imposed in the different sections of Regulation 90 are not all of those which could be required for brake pads, but they at least represent minimums which will initially exclude some manufacturers or products of doubtful quality.

Shear stress machine

REMOVAL AND INSTALLATION OF ROTOR BRAKE PADS FOR VEHICLES OF LESS THAN 3.5t

SAFETY MEASURES

The brake system is a critical element for guaranteeing the safety of the vehicle; all the parts of which it is made up are therefore essential for this purpose.

Any handling of the system must be undertaken with extreme caution and by qualified professionals. Any mistakes in this handling may lead to the complete failure of the system.

These instructions can be used as a guide for the replacement of brake pads, without going into the different set-ups of the systems. If more information is required it is essential to refer to the specific guides for each model or to consult the manufacturer of the friction material.

The brake pads of both wheels of an axle must always be replaced, using the appropriate pads for the model in question. Replacement pads must always be new; second hand material must NEVER be used.

IMPORTANT:

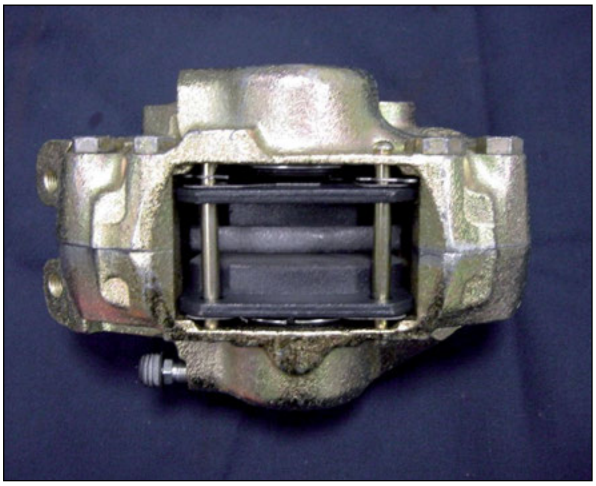
© THE FRICTION MATERIAL OF THE PADS, AS WELL AS THE ROTORS, MUST NOT COME INTO CONTACT WITH MINERAL-BASED GREASES, LUBRICANTS, CLEANERS OR PRODUCTS, AS THEY COULD LEAD TO INEFFICIENCY IN THE BRAKING SYSTEM. IF THIS CONTAMINATION SHOULD OCCUR, IT IS RECOMMENDED THAT THE AFFECTED MATERIAL BE REPLACED.

© FOR THE REPLACEMENT OF THE PADS, SPECIFIC TOOLS MUST BE USED WHICH DO NOT CAUSE DAMAGE TO THE FRICTION MATERIAL AND MUST NOT CONTAIN CUTTING EDGES WHICH COULD DAMAGE THE PADS. THE TIGHTENING VALUES MUST BE THOSE SPECIFIED BY THE MANUFACTURER AND SHOULD BE CARRIED OUT WITH A TORQUE WRENCH.

© ANY TYPE OF FAULT OBSERVED IN THE SYSTEM WHILST INSTALLING THE NEW PADS MUST BE RECTIFIED IN ORDER TO COMPLETELY GUARANTEE THAT THE SYSTEM WORKS CORRECTLY.

REMOVAL OF THE BRAKE PADS FROM A SINGLE PISTON CALIPER AND SLIDING BRIDGE
(THIS PROCEDURE IS VALID FOR CALIPERS WHOSE ACCESS TO THE PADS IS FROM THE UPPER PART)

1. Remove the gripper clips or retaining devices which prevent the pins from coming loose, and disconnect the wear alarm cables, if there are any.
2. Loosen the pins using a claw hammer. Take care if there are springs, clips, etc., as these elements may be under tension and must be removed carefully.
3. Using expander pliers, push the pads backwards, so that they come out of their housing without any problems.
4. Remove the pads from the housing, always starting with the one on the side of the piston.
5. Move the piston as far as it will go so as to be able to install the brake pads.



Dual piston fixed caliper

REMOVAL OF THE BRAKE PADS FROM A SINGLE PISTON CALIPER AND SLIDING BRIDGE

(THIS PROCEDURE IS VALID FOR CALIPERS WHOSE ACCESS TO THE PADS IS FROM THE UPPER PART)

1. Remove the circlips or retaining devices which prevent the pins from coming loose, and disconnect the wear alarm wires, if there are any.
2. Loosen the pins using a claw hammer. Take care if there are springs, clips, etc., as these elements may be under tension and must be removed carefully.
3. Using expander pliers, push the pads backwards, so that they come out of their housing without any problems.
4. Remove the pads from the housing, always starting with the one on the side of the piston.
5. Move the piston as far as it will go so as to be able to install the brake pads.

REMOVAL OF THE BRAKE PADS OF A FLOATING SINGLE-PISTON CALIPER

(THIS PROCEDURE IS VALID FOR CALIPERS WHOSE ACCESS TO THE PADS IS NOT POSSIBLE FROM THE UPPER PART)

1. If there is a wear warning light, disconnect it.
2. Depending on the type of caliper in question, remove the lock screws from the caliper body, which are attached to the pad carrier. These locking elements may be screws, springs, guides or bolts.
3. Using expander pliers or an appropriate lever, push the pads backwards, so that the caliper body comes out of its housing without any problems.
4. Hang the body of the caliper using a hook from the suspension spring. It will not be necessary to remove the hose under any circumstances.
5. Remove the pads from their housing and push the piston as far as it will go so as to be able to install the new pads.

Floating single-piston caliper

THE PROCEDURE BELOW IS COMMON TO ALL TYPES OF CALIPER

IMPORTANT: SPECIAL ATTENTION MUST BE PAID TO THE LOSS OF BRAKE FLUID, BE IT FROM A DAMAGED HOSE OR THE RESERVOIR ITSELF, AS WHEN THE PISTON IS MOVED TO ITS ORIGINAL POSITION THE LIQUID WILL FILL THE RESERVOIR, AND IF THE RESERVOIR IS VERY FULL IT COULD OVERFLOW. IT SHOULD BE REMEMBERED THAT BRAKE FLUID CAN CAUSE SERIOUS DAMAGE IF IT IS NOT HANDLED APPROPRIATELY.

1. In order for the new pads to fit in their housing the pistons must be pushed backwards until they are completely secured in their cavity.
2. For 4-piston fixed calipers or 2-piston floating calipers, the pistons that we have moved to their original position must be prevented from coming out again when we insert the rest of the pistons in their original position.
3. If the brakes are combined, and are made up of the normal system plus a mechanical actuation for the parking brake, it is very important to move the pistons backwards again, either by turning, or by means of a djustment screws, according to the set-up of the caliper.

WARNING:

- COMPRESSED AIR MUST NOT BE USED TO CLEAN THE BRAKES.
- DO NOT CREATE FINE DUST AS ITS INHALATION MAY BE HARMFUL TO YOUR HEALTH.
- USE A MASK WHEN WORKING IN POORLY VENTILATED ENVIRONMENTS.
- USE SPECIALISED BRAKE CLEANING PRODUCTS. IF THESE ARE NOT AVAILABLE, USE METHYL ALCOHOL.

4. Verify the thicknesses of the rotors. If they are below the minimum established by the manufacturer they must be replaced, likewise if large cracks or deep scratches are seen.

INSTALLATION OF THE PADS

1. Before installing the pads, the caliper guides and those which support the pistons must be lubricated with grease which contains a solid lubricant (lithium grease, molybdenum grease, etc.).
2. The wear warning lights must be fitted in their specific housing in the pads.
3. Fit the new brake pads, paying particular attention to how they were fitted, as there are many models which have different positions.
4. Fit the pins, springs and clips in their original position.
5. Connect the wear warning lights to the vehicle cabling.
6. Tighten the mounting screws to the caliper. Whenever possible always use screws with new auto-lock. Tighten them with the torque specified by the manufacturer.

VERIFICATION OF OPERATION

Once the installation of the pads on an axle has been completed, fit the wheels, ensuring that they are given the torque recommended by the manufacturer. Lower the vehicle from the lift and verify the following points:

1. Check the level of the brake fluid, refilling it if necessary.
2. Press the brake pedal repeatedly until it takes effect. Press it as far as it will go and hold it there for a few seconds to check that the pedal does not go down any further, which could indicate that there is a problem in the system.
3. It should be explained to the customer that the first few braking processes should be gentle and gradual, as there should be a period of adaptation of approximately 200 Miles to allow the material to reach its necessary effectiveness.
4. Remember that the brake system must be serviced every 12500 Miles.

IMPORTANT:

ALWAYS TEST THE VEHICLE BEFORE IT IS HANDED OVER TO THE CUSTOMER.

NOTES