CHAPTER 1

INTRODUCTION

1.1 HISTORY OF BRAKING SYSTEM

Ford introduced his model T in 1908 which was the first mass-produced car ever and with it cars became more accessible to ordinary people. Model T was produced with a combustion engine in front of the passengers, four wheels and rear wheel drive. The car weighed 550 kg had a 20-HP engine and a top speed of approximately 65 km/h. It was equipped with a band brake system, a cotton textile band wound around a drum inside the planetary gearbox. The cotton band was lubricated with the oil from the gearbox and in order to avoid over-heating, the driver was instructed to apply the brake in short intervals only.

During 2013, Mercedes Benz introduced S 65 AMG’s class. Designed to be the most luxurious and comfortable car in the world, with 630-hp engine, the sedan can accelerate from 0 to 100 km/h in 4.3s, and its top speed is electronically limited to 250 km/h (for safety reasons). The maximum kinetic energy was now 58 times higher than 105 years earlier, putting enormous demands on the braking performance. The single band brake was replaced by four disc brakes. The present day drivers expect the vehicle braking system to work perfectly under extreme speeds and different environments.
On sports cars, the demands for brake performance are several times higher than on the Mercedes S class. For example, BMW’s Bugatti Veyron Super sport, claimed to be the fastest cars on the market has a top speed of 429 km/h which results in several percentage higher maximum kinetic energy as compared to the Mercedes.

1.2 FUNDAMENTALS OF FRICTION

One of the most interesting and most important physical phenomenons related to brake systems is the lateral force between two rubbing surfaces, i.e. The friction force. If a block is dragged over a horizontal floor, the lateral force required to move the block is equal to the friction force between the two surfaces. In 1490’s Leonardo DA Vinci found that when the normal force on the block increases, the friction force also increases. He furthermore discovered that the friction force between two rubbing surfaces is independent of the apparent, nominal contact area, see Figure 1.1.

Two hundred years later Amonton rediscovered what DA Vinci already had observed and he formulated “Amonton’s laws of friction”:

1. The force of friction is directly proportional to the applied load
2. The force of friction is independent of the apparent area.

These relations between the normal force, \(F_N\), and the lateral force, \(F_L\), can be mathematically formulated as:

\[
\mu = \frac{F_L}{F_N} \tag{1.1}
\]
Where $\mu$ is the coefficient of friction. For many materials this relation is true, within limited load intervals.

![Diagram](image)

**Figure 1.1 Concept of friction.**

In order to explain why the friction force is independent of the nominal contact area, one must study the two facing surfaces. All technical surfaces have a roughness, even if some appears very smooth. If two rough surfaces are pressed against each other, only small parts of them will actually contact each other. Consequently, the area of real contact will be very small. As a matter of fact, the normal load and the hardness of the two materials will define the area of real contact (Eriksson 2000). An increased hardness or a reduced load will lead to a reduced contact area, see Figure 1.2. Thus, for a given material combination, the real contact area depends on the normal load only and has no correlation to the nominal contact area. If the load is doubled, the area of real contact will also be doubled.
Figure 1.2 Contact situations between two rough surfaces. Only small parts of the surfaces are in real contact with each other, encircled. The area of real contact increases with increased load and with decreased hardness (a) Low load and/or high hardness (b) High load and/or low hardness (Jacobson 2004)

In general, the area of real contact is very small. If a 100 x 100 x 200 mm steel cube, with a load of 3 GPa, rests on a flat steel plate, the nominal contact area is, of course 10,000 mm$^2$. The area of real contact, however, is only 0.03 mm$^2$, a factor 300,000 times smaller (Eriksson 2000)

Now, if the friction force is identified as the force required shearing the real contact between the two surfaces, it can easily be understood that the nominal contact area does not affect the friction force. It can also be understood that a doubled normal load, resulting in a doubled area of real contact, will lead to a doubled friction force.

1.3 AUTOMOTIVE BRAKE SYSTEMS

An automotive brake system can be divided into three main parts

1. The rotor, as the name indicates, is rotating with the wheel. It is the first part of the friction couple. Rotors made of grey cast iron have always dominated the market. The last couple of years, other materials, although having only a small commercial importance, have been introduced. Some
examples are SiC-reinforced aluminium, carbon-SiC composites, Al-Cu alloys, Ti-alloy and sintered carbon.

2. The brake lining is the second stationary part of the friction couple. During brake application, the pad is pressed against the rotor with a hydraulic piston. The pressure on the friction lining against the disc produces the stopping power. The pressure on the friction lining against these surfaces results in their contact and interaction under both pressure and heat.

3. The hydraulic system transfers and amplifies the brake force from the brake pedal to the hydraulic piston pressing the linings against the rotor. In modern brakes the hydraulic system also includes the ABS-system (Anti-lock braking system) and different kinds of traction systems.

As mentioned in the introduction, a number of different vehicle brake systems have existed over the years. Today two types reign the market, the disc brake and the drum brake. Drum brakes, being an earlier design, dominated until the 1960’s in all kinds of vehicles. The used of disc brakes in commercial vehicles started in 1973. From this date, front axles of some coaches and travel buses could be equipped with hydraulic disc brakes. The real axles stayed with drum brakes.

The main difference between the two designs is the geometry of the rotor and linings. The hydraulic systems are similar. Figure 1.3 shows a schematic picture of a brake system with one drum and one disc brake.
1.3.1 Drum Brake System

In drum brakes, where the pads (shoes) are pushed outwards against the inside of a drum, the friction force will affect the normal load causing the brake to have either a self-locking tendency or the opposite. In either case, the brake system will get a poor linearity and thus a weak pedal feel. The foremost benefit of the drum brake is the insensitivity for harsh environments, such as water, dirt or road salt.

1.3.2 Disc Brake System

In the disc brake, the linings (also called pads) clamp the disc from opposite sides. The friction force between the pads and the disc are perpendicular to each other and does not affect the normal forces of the pads. Thus, the braking force will depend linearly on the applied normal force, with the premise that the coefficient of friction between the two parts is constant. The result is a superior pedal feel as compared to the drum brake. Another benefit is the lower weight.
Most heavy vehicles use a pneumatic instead of a hydraulic system to apply the brake force. The brake pedal is connected to a gas valve instead of a piston, controlling the pressure drop from the storage tank to the brake cylinder. Pneumatic brakes only require a very low pedal force to apply a high braking force, which is needed to stop a truck or a bus. The drawbacks are poor pedal feel and the size of the system. It requires both an air pump and a storage tank.

1.3.3 Ideal Properties of a Brake Pad

- Coefficient of friction (µ) should be in the range of 0.35 to 0.45 depending on the type of vehicles
- Low fade and high recovery of µ.
- Least sensitivity of µ to load & speed, humidity, water, oils, brake-fluids, temperature etc.
- Moderately low wear
- Good conformability and compatibility with the rotor
- Resistance to vibrations and squealing noise
- High thermal stability
- Should not emit toxic substances to the environment etc

1.4 BRAKE FADE

‘Fade’ is the term used to indicate loss in braking effectiveness at elevated temperatures (typically in the range 300–400 °C), because of a reduction in the friction coefficient (µ). The fade phenomenon in friction materials represents a deviation from the Amonton’s law of friction, and its occurrence reduces braking efficiency and reliability. The symptoms range from less braking effectiveness to a total loss of brakes, sometimes with potentially fatal results.

There is however three very different kinds of brake fade.
1. Green fade
2. Pad fade
3. Fluid fade

1.4.1 Green Fade

This is the type of brake fade caused by hard braking on relatively new pads. With new pads, the resins that bind the friction material will “out-gas” at relatively low temperatures. This is caused by not “bedding” the pads rather than being caused by elevated braking temperatures. Green fade typically occurs much earlier than normal pad fade. Green fade can happen even after changing the brakes and driving normally for many hundreds of miles. The first aggressive stop may result in a loss of friction.

1.4.2 Pad Fade

Pad fade can be caused by several factors. Friction materials are designed to work at an optimum temperature when the coefficient of friction is the highest. When brakes are used too frequently, if the pad material is not adequate for the temperature, then the coefficient of friction can decrease. When the temperature is too high, the material can melt and cause coefficient of friction to rapidly decrease to a point where the material will melt and/or change its frictional characteristics and cause a lubrication effect. Some pad materials change slowly at elevated temperatures while other materials react with a sudden and dangerous loss of friction. The result is “glazed” brake pads and rotors.

1.4.3 Fluid Fade

Fluid fade is caused by overheated brake fluid. The energy converted during braking creates tremendous heat which must be handled by
the rotors, calipers, brake pads and the brake fluid. When the fluid reaches a critical temperature, it boils. Regular brake fluids boil around 400ºF, the best ones are stable up to 500ºF and higher. Whatever the rating, when brake fluid boils, air bubbles are created. Fluid in a closed system cannot be compressed. However, air can be compressed and when boiling brake fluid creates air bubbles, the brake pedal and master cylinder travel is used up compressing the air and thus unable to hydraulically move the pads against the brake rotor.

1.5 Organization of the Thesis

The aim of the work presented in this thesis has been to increase the understanding of the role and the amount of various organic ingredients namely, the resin, organic fibers and organic friction modifiers in the disc brake pad formulation. This understanding is needed to analyze and ultimately solve the fade behavior of the friction composites as the brake pads are highly rated by their resistance to fade.

The work comprises a number of experiments correlated to the Tribology of brake pad materials in brake pad and disc couple. It is presented according to the following outline:

- The Thesis work starts with an introduction to the friction and the contact between two rubbing surfaces. This is followed by a general description of the brake system along with materials and methods for brake pad fabrication and testing.
- Chapter 1 comprises of first part of the thesis, which is about the fundamentals of friction.
- Chapter 2 comprises of second part of the thesis, describing the literature survey carried out.
- Chapter 3 outlines the Fabrication and testing methods of brake pads
• Chapter 4 outlines the study of the change in the molecular weight of the resin in relation to fade and recovery.

• This description is followed by chapter 5, where the effect of selected resin and its amount with respect to fade and recovery is considered.

• Chapter 6 studies the combined effect of organic friction modifier and resin along with the effect of pressure and speed using regression analysis.

• Chapter 7 sketches the influence of type and amount of organic fibers to the generation of fade and wear.

• A summary of the thesis is found Chapter 7.