The material and process requirements in disc brake engineering essay

The disc brake is a device for slowing or stopping the rotation of wheel. Disc brakes can be used on all 4 wheels of vehicle, or combined with disc brakes on the front wheels and drum brakes on the rear.

Before we go in detail about the material selection, I would like to discuss the disc brake operation generally to let us understand how a disc brakes able to operate well.

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

On non-driving wheels, the centre of the brake disc or hub contains the wheel bearings. The hub can be part of the brake disc or a separate assembly between the wheel and hub with nuts or bolts.

On driving wheels, the disc is mounted onto the driving axle and may be held in place by the wheel. On front wheel drive vehicles, it can be mounted on the front hub and wheel bearing assembly. The brake caliper assembly is bolted to the vehicle axle housing or suspension.

Besides that, in most cases the brake is positioned as close as possible to the wheel, but there are exceptions. Some high-performance cars use inboard disc brakes on its rear wheels. The makers claim improved vehicle handling for this design because it reduces unsprung weight.

Moreover, applying brakes can absorb a lot of vehicle energy so friction between braking surfaces generates great heat. Brake parts withstand very high temperatures. Most of the friction area of a disc is exposed to air so cooling is far more rapid than for a drum brake. Unlike with drum brakes, brake fade is rare.

Because of their shape, discs tend to throw off water. So after being driven through water, they operate almost immediately. Disc brakes need much higher pressures to operate than drum brakes, so almost all disc brake systems need a power brake booster to help reduce the pedal forces that are needed from the driver.

Due to the high forces needed to apply a disc brake, using it as a handbrake is less common. Therefore, some vehicles build a drum brake into the centre of the rear disc to provide for park brake operation.

Possible Disc Damage Modes

Discs are usually damaged in one of three ways:

warping

scarring

cracking

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

1. 2. 1 Warping

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

1. 2. 2 Scarring

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

1. 2. 3 Cracking

Cracking is limited mostly to drilled discs, which get small cracks around the drilled holes. These cannot be repaired.

Material Requirement for Disc Brake

Based on the function and the possible disc damage modes above, certain material requirement for disc brake is needed to be taking into consideration. The material requirements for disc brake are as below:

High strength even at elevated temperatures

High stiffness (modulus of elasticity)

Low density

High thermal conductivity

Excellent abrasion resistance

Good creep resistance

2. 0 Material Selection

Based on the material requirement for disc brake in section 1. 3, Metal Matrix Composites has been chosen as the material for automotive disc brakes.

This is because Metal Matrix Composites (MMC) is suitable to use for manufacturing automotive parts such as brake components, brake rotors for high speed trains, bicycles, and others vehicles.

2. 1 Introduction to Metal Matrix Composites

Metal composite materials have found application in many areas of daily life for quite some time. Often it is not realized that the application makes use of composite materials. These materials are produced in situ from the conventional production and processing of metals.

Materials like cast iron with graphite or steel with high carbide content, as well as tungsten carbides, consisting of carbides and metallic binders, also belong to this group of composite materials. For many researchers the term metal matrix composites is often equated with the term light metal matrix composites (MMCs).

Substantial progress in the development of light metal matrix composites has been achieved in recent decades, so that they could be introduced into the most important applications. In traffic engineering, especially in the automotive industry, MMCs have been used commercially in fiber reinforced pistons and aluminum crank cases with strengthened cylinder surfaces as well as particle-strengthened brake disks.

These innovative materials open up unlimited possibilities for modern material science and development; the characteristics of MMCs can be designed into the material, custom-made, dependent on the application. From this potential, metal matrix composites fulfill all the desired conceptions of the designer. This material group becomes interesting for use as constructional and functional materials, if the property profile of conventional materials either does not reach the increased standards of specific demands, or is the solution of the problem. However, the technology of MMCs is in competition with other modern material technologies, for example powder metallurgy. The advantages of the composite materials are only realized when there is a reasonable cost – performance relationship in the component production. The use of a composite material is obligatory if a special property profile can only be achieved by application of these materials.

The possibility of combining various material systems (metal – ceramic – nonmetal) gives the opportunity for unlimited variation. The properties of these new materials are basically determined by the properties of their single components. Figure 1 shows the allocation of the composite materials into groups of various types of materials.

Figure 1 Classification of the composite materials within the group of materials

Although increasing development activities have led to system solutions using metal composite materials, the use of especially innovative systems, particularly in the area of light metals, has not been realized. The reason for this is insufficient process stability and reliability, combined with production and processing problems and inadequate economic efficiency.

Application areas, like traffic engineering, are very cost orientated and conservative and the industry is not willing to pay additional costs for the use of such materials. For these entire reasons metal matrix composites are only at the beginning of the evolution curve of modern materials as shown in Figure 2.

Figure 2 Development curve of the market for modern materials

Metal matrix composites can be classified in various ways. One classification is the consideration of type and contribution of reinforcement components in particle-, layer-, fiber- and penetration composite materials as shown in Figure 3.

Figure 3 Classification of Composite Material with Metal Matrixes

Fiber composite materials can be further classified into continuous fiber composite materials (multi- and monofilament) and short fibers or, rather, whisker composite materials as shown in Figure 4.

Figure 4 Three Shapes of Metal Matrix Composite Materials

2. 2 Reason Selecting Metal Matrix Composites as Material for Disc Brake

There are different types of Metal Matrix Composites in the world. But, not all the type of MMCs is suitable to be taken as material for disc brake. Thus, the type of Metal Matrix Composites that can be selected as material for disc brake due to its attractive material property as below:

Aluminum Matrix Composites

This is the widest group of Metal Matrix Composites. The matrices of Aluminum Matrix Composites are usually based on aluminum-silicon (Al-Si) alloys and on the alloys of 2xxx and 6xxx series which is very suitable to be taken as material for automobile disc brake.

Moreover, Aluminum Matrix Composites able to give properties as show below:

High strength even at elevated temperatures

High stiffness

Low density

High thermal conductivity

Excellent abrasion resistance

Besides that, the ideal Aluminum Matrix Composites stress strain curve for continuous unidirectional fiber composites is presented in Figure 5. Generally, this curve consists of two stages. During the stage I, both fiber and matrix remain elastic, during stage II, the matrix deforms plastically and fibers remain elastic.

There is possibly a stage III where both matrix and fibers deform plastically, but generally the fibers break before their plastic deformation.

Figure 5 Ideal Stress-Strain Curve of a Continuous Fiber metal Matrix Composite

Magnesium Matrix Composite

Magnesium Matrix Composites are reinforced mainly by silicon carbide (SiC) particles (particulate composites).

The material properties of Magnesium Matrix Composites are as below:

Low density

High stiffness

High wear resistance

Good strength even at elevated temperatures

Good creep resistance

Magnesium Matrix Composites are used for manufacturing components for racing cars, lightweight automotive brake system, and aircraft parts for: gearboxes, transmissions, compressors and engine.

According to research by Z. Trojanova . P, Department of physics of Metals, Charles University, he run the experiment on Magnesium Matrix Composites to understand its material properties in a more detail way.

Figure 6 True stress-strain curve

It is interesting to note that the microstructure of AS41/SiC composite exhibits similar features with Mg2Si precipitates on the grain boundaries. Figure 6 shows typical true stress-true strain curve of the ZC63/SiC composite deformed at different temperatures. It can be seen that the flow stress decreases with increasing temperature.

At 200-C, the work hardening is close to zero. This indicates a dynamic balance between hardening and softening. The temperature variations of the yield stress and the tensile strength max are given in Figure 7.

Figure 7 Temperature dependence of the yield stress and the maximum stress

3. 0 Manufacturing Process

There are difference manufacturing process way to produce Metal Matrix Composites and here, I would like to focus on few processes which is more suitable to produce disc brake which made by Metal Matrix composites.

3. 1 Liquid-State Processes

Casting or liquid infiltration involves infiltration of a fibrous or particulate reinforcement pre-form by a liquid metal. Liquid-phase infiltration of MMCs is not straightforward, mainly because of difficulties with wetting the ceramic reinforcement by the molten metal. When the infiltration of a fiber pre-form occurs readily, reactions between the fiber and the molten metal may take place which significantly degrade the properties of the fiber. Fiber coatings applied prior to infiltration, which improve wetting and allow control of interfacial reactions, have been developed and are producing some encouraging results. In this case, however, the disadvantage is that the fiber coatings must not be exposed to air prior to infiltration because surface oxidation of the coating takes place. One liquid infiltration process involving particulate reinforcement, called the Duralcan process, has been quite successful as shown in Figure 8.

Ceramic particles and ingot-grade aluminum are mixed and melted. The melt is stirred slightly above the liquidus temperature (600−700°C). The solidified ingot may also undergo secondary processing by extrusion or rolling. The Duralcan process of making particulate composites by a liquid metal casting route involves the use of 8−12 μm particles. For particles that are much smaller (2−3 μm), the result is a very large interface region and, thus, a very viscous melt. In foundry-grade MMCs, high Si aluminum is used to prevent the formation of the brittle compound Al4C3, which is formed from the interfacial reaction between Al and SiC. Al4C3 is extremely detrimental to mechanical properties, particularly toughness and corrosion resistance.

Figure 8 Casting process for particulate or short fiber MMCs

Alternatively, tows of fibers can be passed through a liquid metal bath, where the individual fibers are wet by the molten metal, wiped of excess metal, and a composite wire is produced. A bundle of such wires can be consolidated by extrusion to make a composite. Another pressure less liquid metal infiltration process of making MMCs is the Primex process which can be used with certain reactive metal alloys such as Al− Mg to infiltrate ceramic pre-forms, Fig. 3. For an Al− Mg alloy, the process takes place between 750−1000°C in a nitrogen-rich atmosphere, and typical infiltration rates are less than 25 cm/h.

3. 2 Squeeze Casting or Pressure Infiltration

Figure 9 Reactive liquid metal infiltration processes

Squeeze casting or pressure infiltration involves forcing a liquid metal into a fibrous or particulate pre-form as shown in Figure 10. Pressure is applied until solidification is complete. By forcing the molten metal through small pores of the fibrous pre-form, this method obviates the requirement of good wet ability of the reinforcement by the molten metal. Composites fabricated with this method have the advantage of minimal reaction between the reinforcement and molten metal because of the short processing time involved. Such composites are also typically free from common casting defects such as porosity and shrinkage cavities.

Infiltration of a fibrous pre-form by means of a pressurized inert gas is another variant of the liquid metal infiltration technique. The process is conducted in the controlled environment of a pressure vessel and rather high fiber volume fractions; complex shaped structures are obtainable (3, 4). Alumina fibers reinforced inter metallic matrix composites, e. g., TiAl, Ni3Al, and Fe3Al matrix materials, have also been prepared by pressure casting (5). The technique involves melting of the matrix alloy in a crucible in vacuum, while the fibrous pre-form is heated separately. The molten matrix material (at ~100°C above Tm) is poured onto the fibers and argon gas is introduced simultaneously. Argon gas pressure forces the melt, which contains additives to aid wetting of the fibers, to infiltrate the pre-form.

Figure 10 Squeeze casting or pressure infiltration process

3. 3 Sinter-Forging

Sinter-forging is a novel and low cost deformation processing technique. In sinter-forging a powder mixture of reinforcement and matrix is cold compacted, sintered, and forged to nearly full density, Figure 11. The main advantage of this technique is that forging is conducted to produce a near-net shape material, and machining operations and material waste are minimized. The low cost, sinter-forged composites have tensile and fatigue properties that are comparable to those of materials produced by extrusion which is suitable for disc brake.

Figure 11 Sinter-Forging techniques for producing near-net shape, low cost MMCs

4. 0 Conclusion

The early Lotus Elise models came with Aluminum Metal Matrix Composite (MMC) brake discs. These brakes were lightweight and a cost effective alternative to the carbon ceramic variations available recently but the only difference is they cannot operate at the same temperatures.

As conclusion, based on the research above, I am confidence to said that Metal Matrix Composites is still the best for automobile disc brake in certain situation.