# Composite materials in automotive brake disc

Abstract – The aim of this paper is to explore the uses of ceramic matrix composites (CMCs) in the automotive industry, their advantages over current grey cast iron discs, their manufacturing processes and potential commercial applications. Cast iron brake discs consume much fuel due to its high specific gravity. As a result, a better and perhaps cheaper alternative is needed to fulfil the needs of high end automotive industries and even mid range consumer vehicles.

## INTRODUCTION

Reducing green house gases and fuel consumption is a common goal for automotive industries and of paramount importance. Auto industries have dramatically increased the use of aluminium in light vehicles in order to reduce weight and help improve efficiency. Aluminium alloy based metal matrix composites (MMCs) with ceramic particulate reinforcement have shown great promise for such applications [1, 2]. These materials having a lower density and higher thermal conductivity as compared to the conventionally used gray cast irons are expected to result in weight reduction of up to 50 – 60 % in brake systems [3]. Under severe service conditions like higher speed, higher load etc, these advanced materials have the potential to with stand these conditions.

## Basic mechanism of mechanical properties

The high fracture toughness or crack resistance mentioned above is a result of the following mechanism: under load the ceramic matrix cracks, like any ceramic material, at an elongation of about 0. 05%. In CMCs the embedded fibres bridge these cracks. This mechanism works only when the matrix can slide along the fibres, which means that there must be a weak bond between the fibres and matrix. A strong bond would require a very high elongation capability of the fibre bridging the crack, and would result in a brittle fracture, as with conventional ceramics.

## Thermal and electrical properties

The thermal and electrical properties of the composite are a result of its constituents, namely fibers, matrix and pores as well as their composition. The orientation of the fibers yields anisotropic data. Oxide CMCs are very good electrical insulators, and because of their high porosity their thermal insulation is much better than that of conventional oxide ceramics. The use of carbon fibers increases the electrical conductivity, provided the fibers contact each other and the voltage source. Silicon carbide matrix is a good thermal conductor. Electrically, it is a semiconductor, and
its resistance therefore decreases with increasing temperature. Compared to (poly)crystalline SiC, the amorphous SiC fibers are relatively poor conductors of heat and electricity.

CMC Brake Discs

Disc brakes are typically made out of grey cast iron. This material is has high tensile strength and can withstand a high temperature before failing. In high performance vehicles the amount of heat generated by friction when braking can be too great so the brakes fail or must be changed often. The failure is due to thermally induced fractures. Also these brakes can be heavy and susceptible to corrosion, which cause failure. Other composites have been tested such as Metal Matrix Composite, and Carbon Carbon Composites. The challenges with these materials are the ability to dissipate heat caused by friction isn’t optimal at high enough temperatures. A typical grey cast iron disc brake can withstand a surface heat of 400 C before failure occurs.

## Type

C/C-SiC is a Carbon fiber phase added to a Silicon Carbide matrix. The resulting material has increased strength with a lower density and high tribological characteristics. The most predominant feature is its ability to withstand high temperatures without failure. Due to its low coefficient of thermal expansion and high thermal conductivity, this CMC can retain its strength at high temperature. This CMC was manufactured as a disc brake with 2D reinforced discontinuous fibers. The fibers are placed perpendicular to the surface of friction to maximize Thermal conductivity. The result is a disc brake that can withstand surfaces temperatures of 1000 C with minimal wear.

## Problems

There are multiple reasons for CMC disk brakes not being implemented among regular cars. Firstly, there is a low demand for high performance brakes due to the brakes themselves being rather expensive. As CMCs gain popularity, the cost of the raw material is expected to reduce, regardless of it being slightly expensive. Since regular cars aren’t used at high speeds, the amount of heat generated with low friction is small. As such, the Carbon Silicon Carbide brakes become inefficient and much weaker particularly in colder conditions. Thermal expansion of the composite and ceramic matrix results in this weakness. Cracking can occur on the surface of the brakes as the material expands at different rates under different temperatures.

ADVANTAGES

The integration of long multi-strand fibres has drastically increased the crack resistance, elongation and thermal shock resistance, and resulted in several new applications. As a result this has overcome the common problems associated with the conventional technical ceramics like alumina, silicon carbide, aluminium nitride, silicon nitride, or zirconia.

Elongation to rupture up to 1%

Strongly increased fracture toughness

Extreme thermal shock resistance

Improved dynamical load capability

Anisotropic properties following the orientation of fibers

In comparison to the conventional grey cast iron brake disk the carbon-ceramic brake disk

Weighed round 50 per cent less reducing the unsprung mass by almost 20 kilograms

Improved brake response and fading data

High thermal stableness

No hot judder

Excellent pedal feel

Improved steering behavior

High abrasion resistance and this longer life time and the advantage of avoiding almost completely brake dust

The table below shows the properties of grey cast iron and its advanced alternatives (SGL Group n. d.)

# Property

# Unit

# Material

C/SiC material, general

C/SiC for carbon-

ceramic brake disk

Gray cast iron (GG-20)

Density

g cm-3

1, 8 … 2, 9

2, 45

7, 25

Tensile strength

MPa (= N mm-2)

10 … 240

20 … 40

200 … 250

Modulus of elasticity

GPa

20 … 240

30

90 … 110

Flexural strength

MPa (= N mm-2)

20 … 210

50 … 80

150 … 250

Elongation at break

%

0. 05 … 0. 8

0. 3

0. 3 … 0. 8

Thermal shock resistance

(second thermal coefficient K’)

W m-1

26. 500 … 46. 000

> 27. 000

< 5. 400

Thermal stability

°C

1350

1350

approx. 700

Maximum operating temperature

(brake disk)

°C

1400

non-oxidizing

900

700

Linear coefficient of thermal expansion

K-1

1. 0 … 3. 5

2. 6 … 3. 0

9 … 12

Thermal conductivity

W m-1K-1

20 … 150

40

54

Specific heat capacity (cp)

kJkg-1K-1

0. 6 … 1. 7

0. 8

0. 5

Manufacturing Processes

There are currently 5 known manufacturing procedures for matrix forming. They are:

## Matrix deposition from a gas phase

## Matrix forming via pyrolysis of C- and Si-containing polymers

## Matrix forming via chemical reaction

## Matrix forming via sintering

## Matrix formed via electrophoresis

Matrix deposition from a gas phase involves a process known as chemical vapour deposition where in the presence of a fibre perform, the deposition takes place between the fibres and their individual filaments and thus called chemical vapour infiltration.

Pyrolysis (Pyrolysis is a thermo chemical decomposition of organic material at elevated temperatures without the participation of oxygen) of C- and Si-containing polymers involves hydrocarbon polymers to shrink during pyrolysis, and upon out gassing form carbon with an amorphous, glass-like structure, which by additional heat treatment can be changed to a more graphite-like structure.

**Matrix formation via chemical reaction works by one material being located between the fibres that react with a second material to form the ceramic matrix.**

**Sintering is used to manufacture oxide fibre/oxide matrix CMC materials. Special precursor liquids are used to infiltrate the pre-form of oxide fibres.**

**In the electrophoresis process, electrically charged particles are dispersed in a special liquid are transported through an electric field into the preform, which has the opposite electrical charge polarity.**

Application in Brake Discs

Carbon/carbon (C/C) materials have found their way into the disk brakes of racing cars and airplanes, and C/SiC brake disks manufactured by the LSI process were qualified and are commercially available for luxury vehicles. The advantages of these C/SiC disks are:

Very little wear, resulting in lifetime use for a car with a normal driving load of 300, 000 km, is forecast by manufacturers.

No fading is experienced, even under high load.

No surface humidity effect on the friction coefficient shows up, as in C/C brake disks.

The corrosion resistance, for example to the road salt, is much better than for metal disks.

The disk mass is only 40% of a metal disk. This translates into less unsprung and rotating mass.

The weight reduction improves shock absorber response, road-holding comfort, agility, fuel economy, and thus driving comfort. The SiC-matrix of LSI has a very low porosity, which protects the carbon fibers quite well. Brake disks do not experience temperatures above 500 °C for more than a few hours in their lifetime. Oxidation is therefore not a problem in this application. The reduction of manufacturing costs will decide the success of this application for middle-class cars.