CERAMIC COMPOSITES FOR AUTOMOTIVE FRICTION DEVICE

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Nevz Ceramics Laboratory

Antonio Chiechi, Ph.D.
e-mail: antonio.chiechi@salentec.com
How do disc brakes work?

Disk brakes convert kinetic energy from the car into thermal energy by friction.
Brake caliper

The brake fluid compresses the piston inside the brake caliper applying pressure to the brake pads.
Brake rotors

- Connected to the axel – rotating at the same speed as the wheel
- Generally made out of steel
- Commonly slotted or drilled for extra heat dissipation
Brake pads

- Fixed in the brake caliper
- Various compounds of materials are used
- Wear over time and must be replaced
Design Challenges

- Increase pad and rotor life
- Reduce brake noise
- Cooling to prevent heat fade
- Maximize braking force
- Federal Safety Requirements
- Environmental Impact

- Passenger Cars:
  - Low noise and wear
- Trucks and SUV’s:
  - Heavier weight requires better braking
- High Performance Cars:
  - Need maximum braking and cooling
Carbon Fiber Reinforced Silicon Carbide (C/\text{SiC})

- C/C Brakes were introduced in aircraft
- Suffered serious disadvantages →
  - Low coefficient of friction below 450 C
  - High rate of wear for the pads

- C/C-SiC
- Woven carbon reinforced carbon core material

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Fig. 1. Structure of the composite brake disc: (a) SEM micrograph of the SiC layer on the C/C composite base and (b) schematic representation of the composite disc.

Manufacture

- Preparation of a C/C composite core
- Liquid silicon infiltration
  - Vacuum
  - High temperature
- SiC layer is formed on the surface of C/C core (depend used process)
- Grinding of the sliding surface of disk
Benefits

• High and consistent frictional coefficients (even with high thermal stress)
• High efficiency on a functional temperature range
• Weight advantage over conventional cast iron components (65%)
• Reduction of unsprung mass (5 Kg/wheel) ➔ exceptional driving behavior
• Not affected by corrosion
• Superior response in all driving conditions
• Long life span (in excess of 300,000 Km)
• No disk distortion or judder
• Early and consistent brake response
• Reduction of the stopping distance
## Disadvantages

- The manufacturing process, although more automated and more refined than when these types of brakes were first created, is still more labor intensive than making brakes based around cast iron rotors.

- These brakes are still not manufactured in the same volume as regular brakes so fewer of them are produced.

- The materials are more exotic, and thus fewer suppliers of raw materials exist.

- These brakes are primarily used on vehicles which demand the releasing of extra heat generated by high performance and heavy vehicles.
  - As for now these brakes can only be found primarily on the more expensive sports cars and luxury vehicles.
  - For these vehicles extra engineering and design work is involved. For example, ball joints, bushings and bearings must also be able to withstand the same amount of heat as the rotors themselves.
  - Engineers have to consider cooling the entire corner of the car.
Contents

- Introduction
  - Ceramic vs conventional braking materials

- Experimental
  - Precursors selection, forming process, reaction bonding

- Results and discussion
  - Microstructural, mechanical and tribolological analysis

- Conclusions
Semi-metallic/Ceramic pads composition

Semi-metallics pads
- **Abrasive** (Al2O3, Glass, Fe2O3, SiO2, Zirconium oxide)
- **Friction modifiers** (Zn, Cu, Pb, Mo, Sb, Ni oxide; Pb, Sb, Cu, Ni sulphate; Graphite, etc.)
- **Fibres and reinforcement** (metallic fibres, Glass fibres, alumina fibres, rubber fibres)
- **Binder** (Epoxy and Phenolic resin, low melting metallic alloy, etc.)

Ceramic Pads
- **Silicon carbide** (Abrasive)
- **Graphite powder** (Friction modifiers)
- **Carbon fibres** (Fibres and reinforcement)
- **Phenolic resin** (Binder)
Problems with state of the art Semi-metallic brake pads

- Variation of CoF(coefficient of friction) with brake temperature;
- Vibrations and noises produced during brake by over-temperature;
- Heavy metals poisoning
- Pollution caused by particular matter produced during brake.

Lost of Safety and efficiency during brake

Environmental concerns
Why to use ceramic pads

Compared with conventional braking materials, ceramic composites offer many promising advantages:

- Higher working temperature (up to 1000° C);
- Lower density (2.5 g/cm³);
- Environmentally friendly behavior since no heavy metal are involved;
- Reduction of polluting emissions;
- Lower variation of CoF with temperature;
Objective

Preliminary study of manufacturing and applications in automotive brake device using a steel disc against ceramic pads

Ceramics pads have been designed and manufactured through reaction bonding technique
Materials

Reactive phase (I)

Inert phase and COF controller

Thermosetting resin as binder during uniaxial pressure

Reactive and toughening phase

Silicon scraps

Chopped carbon fibers

Phenolic Resin

Silicon carbide

Graphite

Reactive phase (II) and lubricant (a part unreacted)
Schematic manufacturing process

1. Identification of precursors
2. Predictive study of final phases knowing initial precursor
3. Mixture of components ball milling system
4. Drying step
5. Uniaxial Moulding pressure of samples
6. Reaction bonding Thermal treatment (up to 1410°C) with silicon scraps

Raw materials are very important on final tribological properties.

The ratio Si/C play an important rule on tribological final properties components.
The Ceramic Matrix Composites (CMC) reinforced with carbon fibers (Cf) were prepared by liquid silicon infiltration process by Reaction Bonding.

Molar ratio of Silicon to Carbon, named subsequently “degree of reaction”.
Granulation and dry forming

- The first suitable mix was homogenized in a ball mill in wet alcoholic medium, adding a novolak phelonic resin, chopped carbon fibers, graphite powders with different granulometry, silicon carbide powder and solid silicon.

- The second step consists in the forming process by die pressing.
Pyrolysis and reactive sintering

- Pyrolysis and the out gassing of the phenolic resin at 800° C in a vacuum oven.

- Reaction bonding is performed placing pyrolised sample and solid silicon scraps in an alumina crucible and bringing them above the melting temperature of silicon, namely 1410° C in non-oxidising and non-nitrifying environment.
Phenolic binder and its pyrolysis

- The selected phenolic resin was NOVOLAK type, because of the reduced quantity of gas produced during pyrolysis.
- Thermogravimetric analysis of the phenolic resin was used to set the pyrolysis temperature program that preserves the sample integrity during the thermal treatment.
- The large amount of defects obtained with 10 wt% resin lead to an optimized resin content of 7 wt%.
Density and porosity

A macroscopic characterization as function of the degree of reaction was performed measuring density and samples porosity by the Archimedean principle.

<table>
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<tr>
<th>Sample</th>
<th>degree of reaction (%)</th>
<th>P(%)</th>
<th>(d_R) (g/cm³)</th>
<th>(d_b) (g/cm³)</th>
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<tr>
<td>MIX.4-SiC0</td>
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<td>1.77</td>
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<td>18.0</td>
<td>2.45</td>
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<td>2.61</td>
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<td>8.10</td>
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<td>MIX.2-SiC40</td>
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<td>MIX.4-SiC45</td>
<td>45</td>
<td>0.65</td>
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<td>2.56</td>
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</tbody>
</table>

Degree of reaction, porosity and apparent density of the samples.
The mechanical characterization has been performed by a universal testing machine; the mechanical tests have been performed by three-points flexure tests.

Samples with dimensions 50x5x3 mm\(^3\) have been analyzed before and after reaction with different reaction degrees.

The higher strength has been obtained for MIX.4 with a reaction degree of 43% (135MPa).
The morphological characterization by SEM has been performed on the samples at each step of the preparation route.

**Figure 1**: SEM image of the green sample (MIX.1) before the two heating steps.

**Figure 2**: Sample (SiC40) evidence of hexagonal SiC grain growth after reaction bonding.

**Figure 3**: Sample (SiC45) after reaction at 1500°C; carbon fibres are distinguishable.
Coefficient of friction

- COF = coefficient of friction is the ratio within pressure force (W) and Friction Force (F)
  \[ \mu = \frac{F}{W} \]
  \[ 0 < \mu < 1 \]

- The coefficient of friction is strongly influenced by the roughness of the surface, the hardness of the material and the temperature
Friction meccanism

- Deformation-abrasion: penetration of hard asperities of one surface over another and the consequent generation of grooves;
- Erosion wear: solid or liquid particle impact on interface contact;
- Fatigue surface: due to the application of cyclic loading that in correspondence of defects tend to generate cracks;
- Melting: due the high temperature reached on interface;
- Oxidation: oxide coating on contact interface due the high temperature.
Tribological properties have been studied with dynamometer machine.

The “coefficient of friction” (COF), i.e. the ratio between horizontal force on the pad and the pad-disc applied pressure, was obtained measuring the torsion moment experienced by a rotating stainless steel disk in contact with the CMC pad.

The COF has been measured for the sample prepared with MIX.4 and degree of reaction of 23%, for which the best results were expected. The COF exhibits values between 0.35 and 0.50.
Tribological Testing methods

The kinetic energy adsorbed by brake was supplied by the inertia wheels which were by motors.

When the intertial wheel, which rotated with the rotor simultaneously, was accelerated to a certain rotational velocity, the brake was achieved through the friction between the rotor and stator.

Parameter:
Brake pressure(N);
Rotation speed(m/s);
Torque moment(Nm);

Rotating velocity, brake moment, and brake time were recorded by computer.

Fig. 4. Schematic diagram of dynamometer. (1) inertial wheel, (2) bearing, (3) clutch, (4) rotor holder, (5) rotor, (6) stator (C/C–SiC), (7) pressing cylinder, (8) strap, (9) motor, and (10) lathebed.
Simulation road test(I)

Two consecutive two-minutes braking

Torque moment constant

Pressure costant

Cold on
Cold off

COF 0.35-0.50
Simulation road test(II)

Pressure constant

COF 0.40-0.50
Simulation road test(III)

Pressure constant

COF 0.35-0.50
After one second the coefficient of friction reaches the average value of about 0.45, a little above the commercial brake pads.

After 5 seconds it reaches about 0.50.

COF, is comparable with that of ordinary pad.

The COF variation versus time for ceramic pad on steel
The coefficient of friction doesn’t change with temperature up to the highest temperature achieved during measurement (450° C); this is a very important factor for brake efficiency estimation.

The COF variation versus time for ceramic pad on steel.
Conclusions

- The developed production process has several advantages in terms of versatility and time if compared with the conventional techniques such as Chemical Vapour Deposition (CVD).

- A novolak phenolic resin was used as binder and carbon precursors. A proper control of phenolic resins content and reactivity was achieved.

- By varying the silicon amount in the liquid infiltration step, it is possible to modulate the hardness, mechanical and tribological properties.

- COF, between 0.35 and 0.50, has been obtained. It has been evidenced that the friction coefficient variation with temperature is very low in C\textsubscript{f}/C-SiC composites pads if compared with the commercially available brake pads which suffer a relevant reduction of COF with temperature.
References


- High Performance Automotive Brakes. 28 Sep. 2006. SGL Technologies Website. 2005

http://www.sglcarbon.com/sgl_t/brakedisc/index.html