Ceramic Matrix Composites-
Manufacturing and Applications in the
Automotive Industry

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CMCs Introduction

- Combination of covalent and ionic bonding between metallic and non-metallic elements
- High stiffness, low density, chemical inertness, thermal stability, good insulators, etc.
- Operation over a wide range of temperatures
- Lack of toughness and brittleness → catastrophic failure at low strains (<1%)

Fibre Reinforced Ceramics

- Fibre reinforcements can be used to improve the toughness of a material

- High temp. in processing (and service) of CMC components
  - Temperature resistance
  - Chemical compatibility
  - Thermal expansion mismatch

# Processing and Manufacture

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<th>Cold-Pressing and Sintering</th>
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- Liquid/melt
- Gas
Non-Reactive Liquid Infiltration

- Melt Infiltration
  - Single step
  - High density
  - High melting temperatures
  - High viscosities
Reactive Liquid Infiltration

- Liquid silicon infiltration (LSI)
  - First developed in late 1980s
  - Infiltration of C green-body with molten Si
    \[ C_{(s)} + Si_{(l)} \rightarrow SiC_{(s)} \]

Gas Infiltration

- Chemical Vapour Impregnation (CVI)

<table>
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<tr>
<th>Ceramic Matrix</th>
<th>Precursors</th>
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<tr>
<td>SiC</td>
<td>$CH_3SiCl_3$</td>
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<tr>
<td>$Si_3N_4$</td>
<td>$SiCl_4 + NH_3$</td>
</tr>
<tr>
<td>$Al_2O_3$</td>
<td>$AlCl_3 + CO_2$</td>
</tr>
<tr>
<td>ZrO$_2$</td>
<td>$ZrCl_4 + CO_2$</td>
</tr>
<tr>
<td>TiB$_2$</td>
<td>$TiCl_4 + BCl_3$</td>
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</tbody>
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- Almost any ceramic can be formed
- Near-net shape
- Slow process (diffusion)
- High cost

Automotive Ind. - Braking systems

- Ceramic composite brakes: C/SiC
  - High braking performance
  - Low weight (2.4 g/cm³)
  - Low wear rate
  - Operating temperatures 1,400°C

- First studied in 1990s, available in 2000s
  - Porsche 911 GT2 (2001) (PCCB)

- 50,000-70,000 CMC brake discs manufactured in 2006
  - SICOM™, BREMBO™, etc.

- High Cost

Automotive Ind.- Clutches

- Porsche Ceramic Composite Clutch (PCCC)
  - Specially designed for the Carrera GT
  - Siliconized carbon fibre fabrics
  - 169 mm- diameter, 3.5 kg
  - One tenth of mass moment of inertia
  - Lower transmission and engine mounting → Lower centre of gravity
  - High cost


Limitations and Future Challenges

- CMCs offer a unique set of properties, especially at high temperatures.

- Progress in manufacturing, such as LSI process, has made CMCs available in areas such as automotive.

- The high costs is the main barrier for further penetration in more cost-sensitive areas.

- Development of new tech. to lower processing temperatures.

- Automation.