

# 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%)

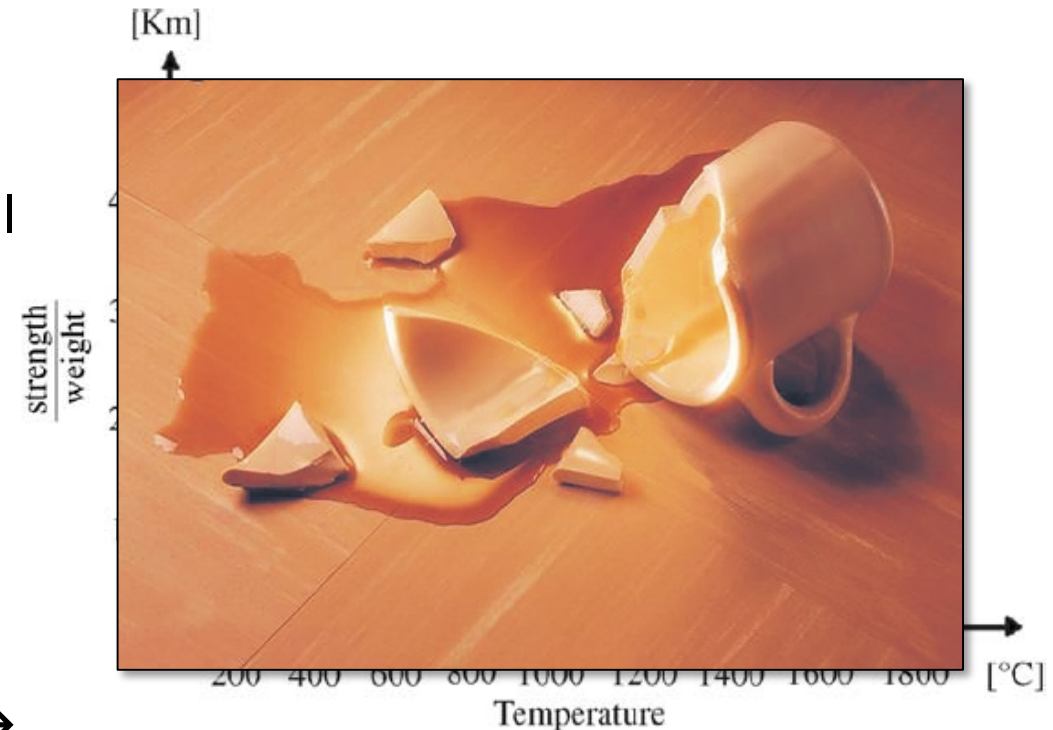
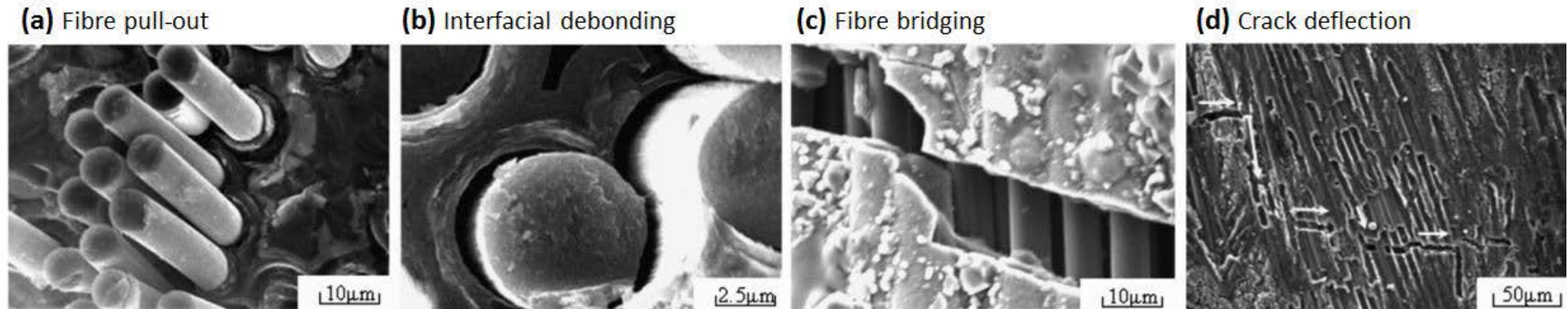


Image from <http://brokenstringsandprettythings.wordpress.com/>  
(Accessed 11/01/2014), Acta Astronaut. 55, 409 (2004).

# Fibre Reinforced Ceramics

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



S. Fan, et al., Compos. Sci. Technol. 67, 2390 (2007).

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

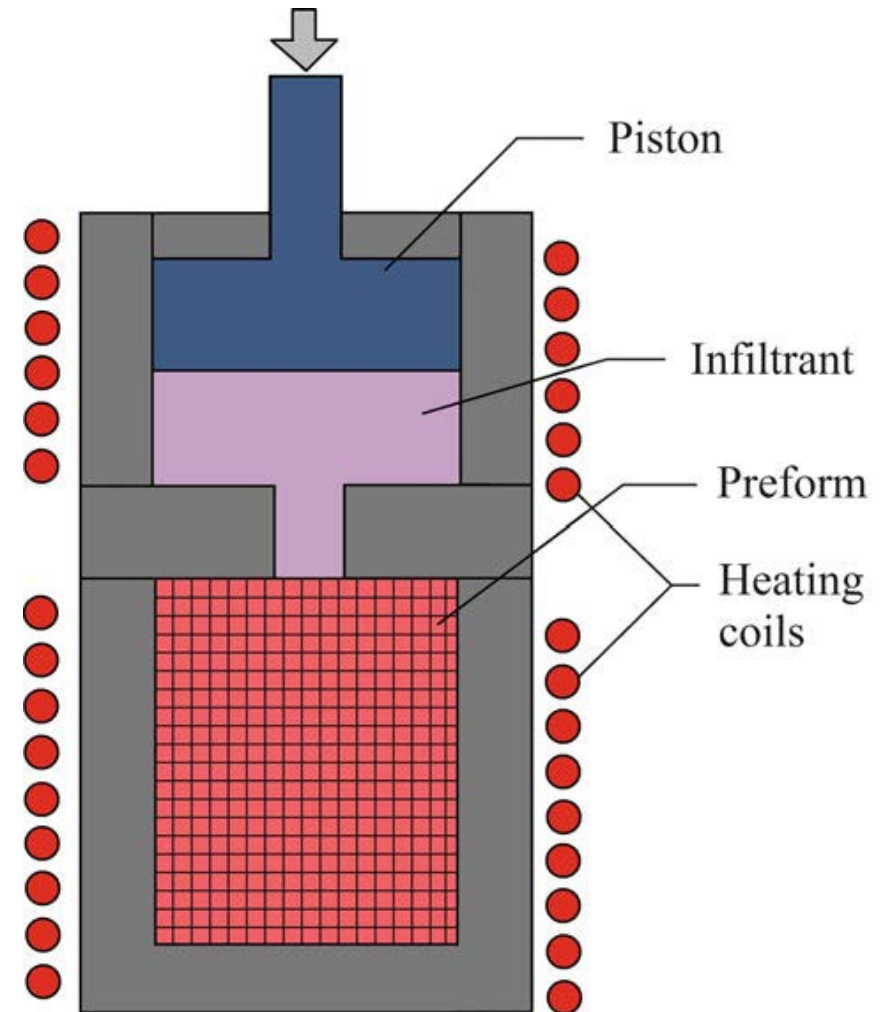
# Processing and Manufacture

<b>Conv. Ceramic Consolidation</b>	Cold-Pressing and Sintering	
<b>Prepreg form</b>	Slurry Impregnation and Hot-Pressing	
<b>Porous Preform Infiltration</b>	<b>Melt Infiltration</b>	Liquid/melt
	Sol-Gel Infiltration	
	Polymer Infiltration and Pyrolysis (PIP)	
	<b>Reactive Liquid Infiltration</b>	
	Directed Oxidation/Nitridation (Lanxide™)	
	Reaction Bonding	Gas
<b>Chemical Vapor Infiltration (CVI)</b>		

# Processing and Manufacture

## Non-Reactive Liquid Infiltration

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

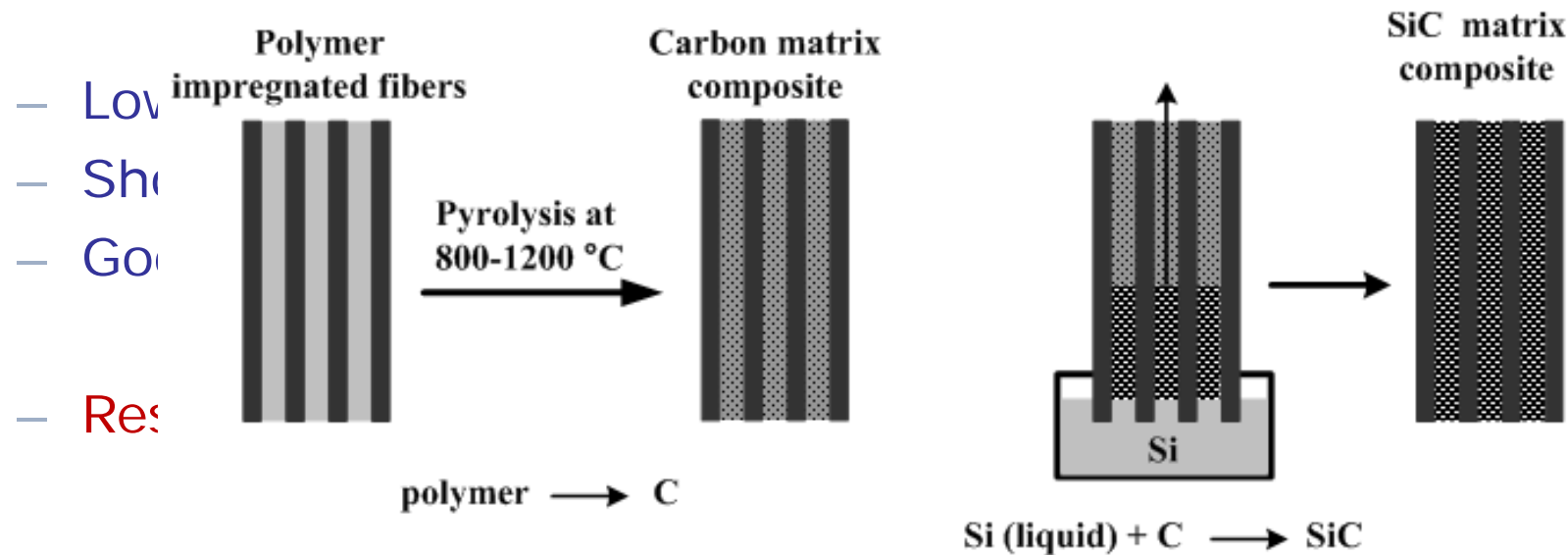
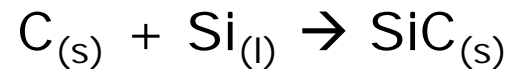


K. K. Chawla, in *Compos. Mater.*, 3rd ed.  
Springer New York, New York, NY, 2012

# Processing and Manufacture

## Reactive Liquid Infiltration

- Liquid silicon infiltration (LSI)
  - First developed in late 1980s
  - Infiltration of C green-body with molten Si



D. Kopeliovich, available at <http://www.substech.com/>  
 (Accessed 11/11/2014)

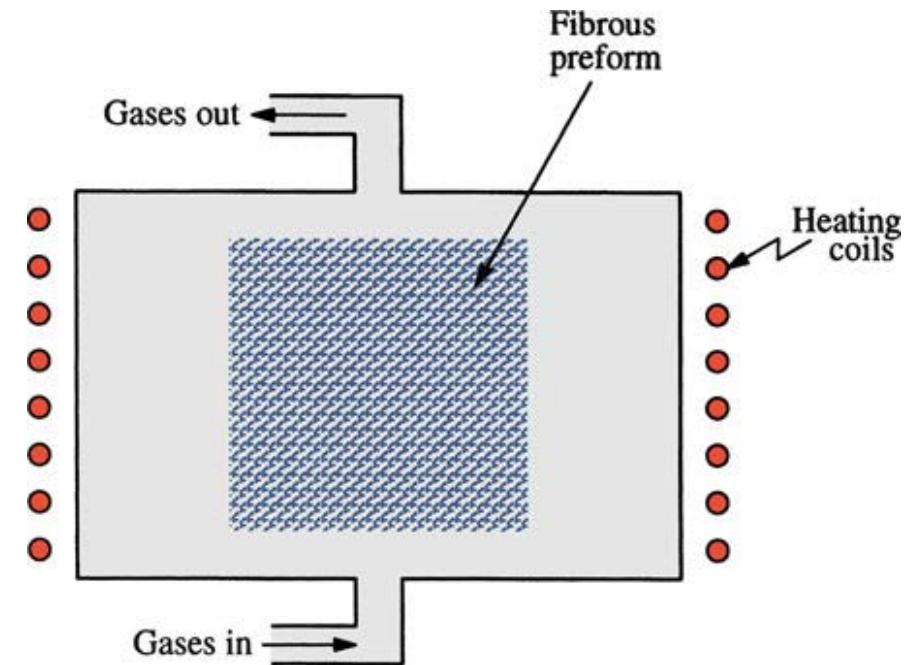
# Processing and Manufacture

## Gas Infiltration

- Chemical Vapour Impregnation (CVI)

Ceramic Matrix	Precursors
$SiC$	$CH_3SiCl_3$
$Si_3N_4$	$SiCl_4 + NH_3$
$Al_2O_3$	$AlCl_3 + CO_2$
$ZrO_2$	$ZrCl_4 + CO_2$
$TiB_2$	$TiCl_4 + BCl_3$

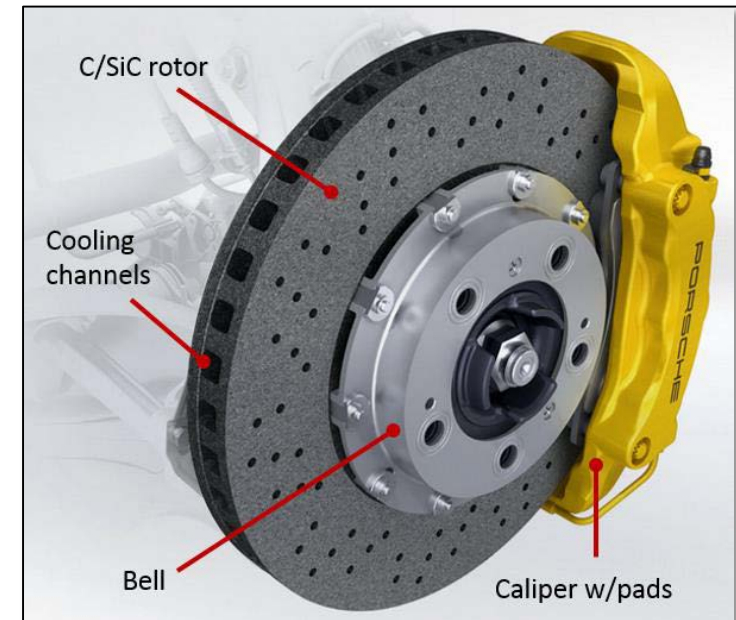
- Almost any ceramic can be formed
- Near-net shape
- Slow process (diffusion)
- High cost



K. K. Chawla, in *Compos. Mater.*, 3rd ed.  
Springer New York, New York, NY, 2012

# Automotive Ind.- Braking systems

- Ceramic composite brakes: C/SiC
  - High braking performance
  - Low weight (2.4 g/cm<sup>3</sup>)
  - Low wear rate
  - Operating temperatures 1,400°C
- First studied in 1990s, available in 2000s
  - Mercedes CL 55 AMG F1 Lim. Ed. (2000)
  - Porsche 911 GT2 (2001) (PCCB)
- 50,000-70,000 CMC brake discs manufactured in 2006
  - SICOM™, BREMBO™, etc.
- **High Cost**

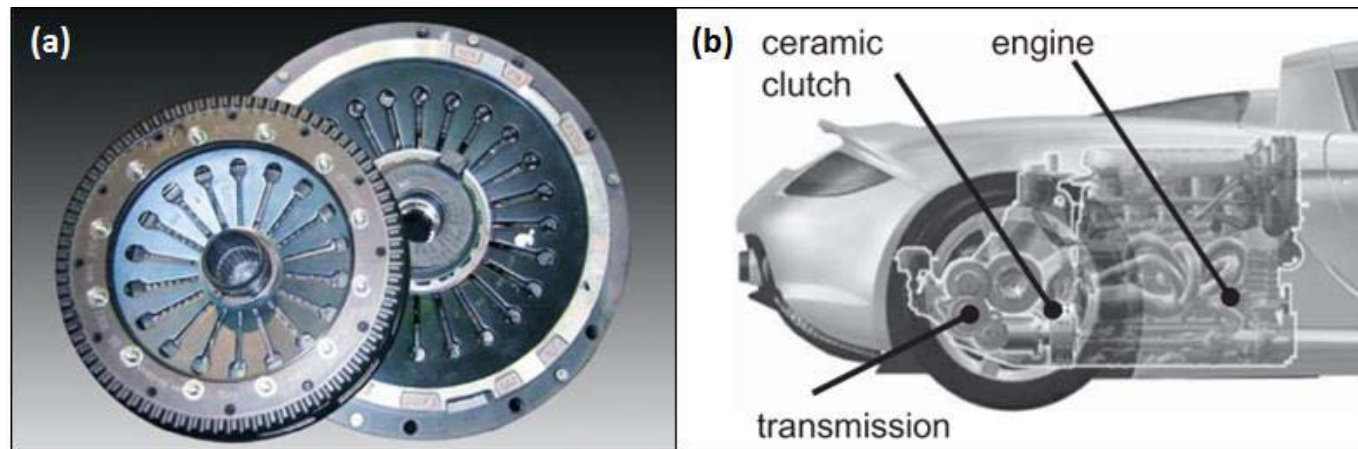


Porsche Cars Great Britain Ltd.,  
available at <http://www.porsche.com/uk/>  
(Accessed 15 Oct 2014).



# 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**



W. Krenkel and F. Berndt,  
Mater. Sci. Eng. A 412, 177 (2005)

W. Krenkel and R. Renz, in *Ceram. Matrix Compos.*  
Wiley-VCH, Weinheim, Germany, 2008

# Limitations and Future Challenges

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- 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