CERAMIC MATRIX COMPOSITES (INTRODUCTION)

According to the classification of composite materials:
Ceramic Matrix Composite (CMC) is a material consisting of a ceramic matrix combined with a ceramic (oxides, carbides) dispersed phase.
Ceramic Matrix Composites are designed to improve toughness of conventional ceramics, the main disadvantage of which is brittleness.
Ceramic Matrix Composites are reinforced by either continuous (long) fibers or discontinuous (short) fibers.
Short-fiber (discontinuous) composites are produced by conventional ceramic processes from an oxide (alumina) or non-oxide (silicon carbide) ceramic matrix reinforced by whiskers of silicon carbide (SiC), titanium boride (TiB_2), aluminum nitride (AlN), zirconium oxide(ZrO_2) and other ceramic fibers. Most of CMC are reinforced by silicon carbide fibers due to their high strength and stiffness (modulus of elasticity).
Whiskers incorporated in a short-fiber Ceramic Matrix Composite improve its toughness resisting to cracks propagation. However a character of failure of short-fiber reinforced materials is catastrophic.

Long-fiber (continuous) composites are reinforced either by long monofilament of long multifilament fibers.

The best strengthening effect is provided by dispersed phase in form of continuous monofilament fibers, which are fabricated by chemical vapor deposition (CVD) of silicon carbide on a substrate made of tungsten (W) or carbon (C) fibers.
Monofilament fibers produce stronger interfacial bonding with the matrix material improving its toughness. Failure of long-fiber Ceramic Matrix Composites is not catastrophic.

Typical properties of long-fiber Ceramic Matrix Composites:

- High mechanical strength even at high temperatures;
- High thermal shock resistance;
- High stiffness;
- High toughness;
- High thermal stability;
- Low density;
- High corrosion resistance even at high temperatures.

Ceramic composites may be produced by traditional ceramic fabrication methods including mixing the powdered matrix material with the reinforcing phase followed by processing at elevated temperature: hot pressing, sintering.
Such fabrication routs are successfully employed for preparing composites reinforced with a discontinuous phase (particulate or short fibers). However the composites reinforced with continuous or long fibers are rarely fabricated by conventional sintering methods due to mechanical damage of the

fibers and their degradation caused by chemical reactions between the fiber and matrix materials at high sintering temperature. Additionally sintering techniques result in high porosity of the fiber reinforced composites.

Ceramic matrix composites reinforced with long fibers are commonly fabricated by infiltration methods. In this group of fabrication techniques the ceramic matrix is formed from a fluid (gaseous or liquid) infiltrated into the fiber structure (either woven or non-woven).
Prior to the infiltration with a ceramic derived fluid the reinforcing fibers surface is coated with a debonding interphase providing weak bonding at the interface between the fiber and matrix materials. Weak bonding allows the fiber to slide in the matrix and prevents brittle fracture.

Matrix material for long-fiber (continuous fiber) composite may be silicon carbide ceramic, alumina (alumina-silica) ceramic or carbon.

- **Silicon carbide matrix composites** are fabricated by chemical vapor infiltration or liquid phase Infiltration methods of a matrix material into a preform prepared from silicon carbide fibers.

Silicon carbide matrix composites are used for manufacturing combustion liners of gas turbine engines, hot gas re-circulating fans, heat exchangers, rocket propulsion components, filters for hot liquids, gas-fired burner parts, furnace pipe hangers, immersion burner tubes.

- **Alumina and alumina-silica (mullite) matrix composites** are produced by sol-gel method, direct metal oxidation or chemical bonding.

Alumina and alumina-silica (mullite) matrix composites are used for manufacturing heat exchangers, filters for hot liquids, thermo-photovoltaic burners, burner stabilizers, combustion liners of gas turbine engines.

- **Carbon-Carbon Composites** are fabricated by chemical vapor infiltration or Liquid phase infiltration methods of a matrix material into a preform prepared from carbon fibers.

Carbon-Carbon Composites are used for manufacturing high performance braking systems, refractory components, hot-pressed dies, heating elements, turbojet engine components.

Properties of some Ceramic Matrix Composites

(Materials Data)

- Typical SiC Matrix Composite reinforced by SiC long fibers
- SiC Matrix Composite reinforced by SiC long fibers (cg-Nicalon)
- SiC Matrix Composite reinforced by SiC long fibers (Hi-Nicalon)
- SiC Matrix Composite reinforced by SiC long fibers (Hi-Nicalon type S)
- SiC Matrix Composite reinforced by SiC long fibers (Dow Sylramic)
- Typical Alumina Matrix Composite reinforced by SiC long fibers
- Alumina Matrix Composite reinforced by SiC whiskers
- Carbon-Carbon Composite (randomly oriented fibers)
- Carbon-Carbon Composite (uni-directional fibers)

- Carbon-Carbon Composite (bi-directional fibers)
- Carbon-Carbon Composite (3D structure)

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