Lecture 6.1: Ceramic Matrix Composites

Introduction
The word ceramic is derived from the Greek word *keramikos*. *Keramikos* is used to refer to pottery. In general, ceramics may be defined as solid materials which exhibit very strong ionic bonding and in few cases covalent bonding. Ceramic materials are typically crystalline in nature. Ceramics are inorganic and non-metallic solids that are typically available in the form of powder materials. Monolithic ceramic materials possess several desirable properties, such as high moduli, high compressive strength, high temperature capability, high hardness and wear resistance, low thermal conductivity and chemical inertness. The high temperature proficiency of ceramics makes these materials very attractive for extremely high temperature applications. However, owing to their very low fracture toughness, ceramics are not appropriate for structural applications. When ceramic materials are subjected to mechanical or thermal loading, catastrophic failure takes place because ceramics do not exhibit plastic deformation as metals plastically deform due to their high mobility of dislocation. Even a minor crack can propagate so quickly or can grow to critical sizes that result in a sudden failure. Such type of failure in ceramic materials occurs because of one deadly characteristic, namely, lack of toughness.

Thus, one of the prime purposes of producing ceramic matrix composites is to improve the toughness. The main purpose of using reinforcement (such as fibers, particles and whiskers) in polymer matrix composites (PMCs) and metal matrix composites (MMCs) is to increase the strength of the composites whereas, the reinforcement used in ceramic matrix composites (CMCs) increases toughness of the composites.

By definition *ceramic matrix composites* are materials in which one or more distinct ceramic phases are intentionally added to another, in order to enhance some property that is not possessed by the monolithic ceramic materials. In ceramic matrix composites, a given ceramic matrix is reinforced with either discontinuous reinforcement, such as particles, whiskers or chopped fibers or with continuous fibers. The basic reinforcements which are included in the ceramic matrices are carbon, glasses, glass-ceramics, oxides and non-oxides. The main function of the matrix is to keep the reinforcing phase in the desired orientation or location and act as a load transfer media as well as protect reinforcement from the environment. Whereas, the primary aim of the reinforcement is to provide toughness to an otherwise brittle matrix. Filler materials in particle
form are also sometimes added to the matrix materials during the processing of CMCs to enhance the properties such as electrical conductivity, thermal conductivity, thermal expansion and hardness. Particles with different shapes such as spherical, irregular and faceted are commonly used during the processing of CMCs. The schematic of morphology of the different particulate reinforcements is shown in Figure 1.

![Particulate morphology](image)

**Figure 1** Particulate morphology (a) Spherical (b) Irregular (c) Faceted

Ceramic matrix composites (CMCs) can be processed either by conventional powder processing technique or by other more specific and customized techniques. The processing temperature for CMCs is extremely high compared to polymer or metal matrix composites which leads to a very difficult and expensive processing. Some advantages and disadvantages of using ceramic matrix composites are listed below:

**Advantages of ceramic matrix composites**

- a) Excellent wear and corrosion resistance in a wide range of environments and temperatures
- b) Higher strength to weight ratio
- c) Higher strength retention at elevated temperature
- d) Higher chemical stability
- e) Non-catastrophic failure
- f) High hardness
- g) Lightweight

**Disadvantages of ceramic matrix composites**

- a) Processing routes for CMCs involve high temperatures – can only be employed with high temperature reinforcements
b) CMCs are designed to improve toughness of monolithic ceramics, the main disadvantage of which is brittleness

c) High processing temperature results in complexity in manufacturing and hence expensive processing

d) Difference in the coefficients of thermal expansion between the matrix and the reinforcement lead to thermal stresses on cooling from the processing temperatures

Applications
Ceramic matrix composites overcome the major demerits (such as brittle failure, low fracture toughness and limited thermal shock resistance) of monolithic ceramics. Therefore, the use of these materials has captured the fields where high temperature and excellent wear and corrosion resistance are the principal matters of concern. One of the most important applications of ceramic matrix composites is in production of cutting tools which are made up of SiC whisker reinforced aluminium oxide for machining of hard to machine materials. Moreover, ceramic matrix composites are widely used in several engineering applications such as in heat shield systems, gas turbines components (combustion chambers, stator vanes and turbine blades), rocket engines, components for burners, flame holders, hot gas ducts, brake disks and brake system components for airplanes or cars which experience extreme thermal shock, bearing components that necessitate high corrosion and wear resistance.