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An Overview of Ceramic Matrix Composite

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ABSTRACT
Ceramic materials often exhibit a combination of useful physical and mechanical properties, including high refractoriness, but their applications are restricted due to their brittle behavior; in an attempt to improve the strength, and particularly the toughness, of brittle ceramics particle-strengthening and fiber-reinforcement have been utilized, with limited success. The factors which affect the mechanical properties of these composite systems are discussed, and the various experimental systems that have been investigated are reviewed. It is concluded that, although the potential applications of such materials are extremely diverse, several important aspects, particularly the effect that matrix microcracking may have on the mechanical and thermal stability of reinforced-ceramic systems, must be fully evaluated before ceramic-matrix composites can seriously be considered as useful replacements for more conventional materials.

Keywords: aluminum nitride, ceramic fiber reinforced ceramic, ceramic matrix composite, material, silicon carbide, titanium boride

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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 covnalent 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 [1]. 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 [2]. 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 [3].

Ceramic matrix composites (CMCs) are a subgroup of composite materials. They consist of ceramic fibers embedded in a ceramic matrix, thus forming a ceramic fiber reinforced ceramic (CFRC) material. The matrix and fibers can consist of any ceramic material. CMC materials were designed to overcome the major disadvantages such as low fracture toughness, brittleness, and limited thermal shock resistance, faced by the traditional technical ceramics. Ceramic matrix composites (CMCs) are a subgroup of composite material as well as a subgroup of technical ceramic [4]. They consist of ceramic fibers embedded in a ceramic matrix, thus forming a ceramic fiber reinforced ceramic (CFRC) material. Ceramic materials often exhibit a combination of useful physical and mechanical properties, including high refractoriness, but their applications are restricted due to their brittle behavior. In an attempt to improve the strength, and particularly the toughness, of brittle ceramics particle-strengthening and fiber-reinforcement have been utilized, with limited success. Ceramic Matrix Composites are reinforced by either continuous (long) fiber or discontinuous (short) fiber. 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 (TiB2), aluminum nitride (AlN), zirconium oxide (ZrO2) and other ceramic fibers. Most of CMC are reinforced by silicon carbide fibers due to their high strength and stiffness. However, a character of failure of short-fiber reinforced materials is catastrophic (causing a lot of damage) [5]. 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 [6].

Properties of ceramic matric materials:

- High strength.
- High fracture toughness.
- High hardness.
- Excellent wear resistance.
- Good frictional behavior.
- Anti-static.

Advantages of 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.

Disadvantages of Ceramic Matrix Composites

- Processing routes for CMCs involve high temperatures – can only be employed with high temperature reinforcements.
- CMCs are designed to improve toughness of monolithic ceramics, the main disadvantage of which is brittleness.
- High processing temperature results in complexity in manufacturing and hence expensive processing.
- Difference in the coefficients of thermal expansion between the matrix and the reinforcement lead to thermal stresses on cooling from the processing 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. 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 inter phase 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 [7–9].

Matrix material for long-fiber composite may be:

- Silicon carbide ceramic
- Alumina and alumina-silica matrix
- Carbon-carbon composite

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. It is useful in manufacturing combustion liners of gas turbine engines, hot gas re-circulating fans, gas-fired burner parts' filters for hot liquids.

Alumina and alumina-silica (mullite) matrix composites are produced by sol-gel method, direct metal oxidation or chemical bonding. It is useful in manufacturing heat exchangers ′ burner stabilizers, thermo-photovoltaic burners, filters for hot liquids
Carbon-carbon composite are fabricated by chemical vapor infiltration or Liquid phase infiltration methods of a matrix material into a preform prepared from carbon fibers. It is useful for refractory components, hot-pressed dies, heating elements [10].

Applications of Ceramic Composite Materials

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.

Cutting Tools

Aerospace

Jet Engine

Burner

Turbine Blade

Hot Fluid Channel

Other applications and developments**:**

- Thrust control flaps for military jet engines
- Components for fusion and fission reactors
- Friction systems for various applications
- Nuclear applications [10]

CONCLUSIONS

The advanced ceramics developed during the last three decades were initially found to have some favorable properties which prompted intensive work for their use as high temperature structural part in process industries and in heat conversion devices.

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