Ceramic Matrix Composite

Ceramic matrix composites (CMCs) are a subgroup of composite materials as well as a subgroup of ceramics. They usually consist of ceramic fibers, whiskers, particles embedded in a ceramic matrix phase.

The desirable characteristics of (CMCs) include high-temperature stability، high thermal shock resistance, high hardness, high corrosion resistance، lightweight, nonmagnetic and nonconductive properties, and the versatility in the providing unique engineering solutions. In a brittle matrix, like ceramics, the matrix carries most of the load, which is usually compressive (like in teeth or bone), but it suffer from the catastrophic fracture when subjected to dynamic and mechanical loads.

The motivation to develop (CMCs) was to overcome the problems associated with the conventional technical ceramics like alumina, silicon carbide, aluminum nitride, silicon nitride or zirconia which they fracture easily under mechanical or thermo-mechanical loads because of cracks initiated by small defects or scratches. In ceramics, the crack resistance is very low and in order to increase the crack resistance or (fracture toughness), fibers, whiskers and particles are embedded into the matrix.

Fracture toughness is a property, which describes the ability of a material containing a crack to resist fracture, and is one of the most important properties of any material for the virtually all design engineering applications. It is denoted (K_{IC}) and has the units of ($MPa.m^{0.5}$).

The fracture toughness values for ceramic materials are low and typically lie between (1 to 5 $MPa.m^{0.5}$). By way of contrast, fracture toughness (K_{Ic}) values for the most metals are much higher [15 to greater than 150 $MPa.m^{0.5}$. The fracture toughness of ceramics have been improved significantly by development of a new generation of the ceramic-matrix composites ,particulates, fibers، or whiskers of one ceramic material that have been embedded into a matrix of another ceramic.

Ceramic-matrix composite have extended fracture toughness to between about (6 and 20) $MPa.m^{0.5}$. In essence, this improvement in fracture properties results from interactions between advancing cracks and dispersed phase particles.

The crack initiation normally occurs with the matrix phase, whereas crack propagation is impeded or hindered by particles، fibers, or whiskers. Several techniques are used to retard crack propagation, which are discussed as follows.

• Toughening Mechanism by Phase Transformation

One particularly interesting and promising toughening technique employs a phase transformation to arrest the propagation of the cracks and is aptly termed the transformation toughening. In this technique, small particles of (CaO, MgO, Y_2O_3, and CeO) are used as stabilized phase in order to stabilize preferred phases in partially stabilized zirconia (ZrO_2).

Partial stabilization allows retention of the metastable tetragonal phase at the ambient conditions rather than the stable monoclinic phase ؛the net result is that compressive stresses are established on the crack surfaces near the crack tip that tend to pinch the crack shut، thereby arresting its growth.

• Toughening Mechanism by Ceramic Whiskers

Other recently developed toughening techniques involve the use of ceramic whiskers، often SiC or Si_3N_4. These whiskers may inhibit crack propagation by (1) deflecting crack tips, (2) forming bridges across crack faces, (3) absorbing energy during pullout as whiskers debond from the matrix, and/or (4) causing a redistribution of the stresses in regions adjacent to the crack tips. In general, increasing the fiber content improves the strength and the fracture toughness of ceramics. Furthermore, there is a considerable reduction in the scatter of fracture strengths for whisker-reinforced ceramics relative to their unreinforced counterparts.

In addition, these CMCs exhibit improved high-temperature creep behavior and resistance to thermal shock (i.e., failure resulting from sudden changes in temperature). Ceramic-matrix composites may be fabricated using hot pressing, hot isostatic pressing, and liquid phase sintering techniques. Relative to applications, (SiC) whisker reinforced alumina are being used as the cutting-tool inserts for machining hard metal alloys; tool lives for these materials are greater than for cemented carbides.

• Toughening Mechanism by Ceramic Fibers

However, the improvement was limited, and the products have found application only in some ceramic cutting tools. So far, only, the integration of long multi-strand fibers has drastically increased the crack resistance, elongation and thermal shock resistance, and resulted in several new applications. The reinforcements used in the ceramic matrix composites (CMC) serve to enhance the fracture toughness of the combined material system while still taking the advantage of the inherent high strength and Young's modulus of ceramic matrix. The most common reinforcement embodiment is a continuous-length ceramic fiber, with an elastic modulus that is typically somewhat higher than the matrix.

The functional role of this fiber is (1) to increase the CMC stress for progress of micro-cracks through the matrix, thereby increasing the energy expended during crack propagation; and then (2) when thru-thickness cracks begin to form across CMC at a higher stress (proportional limit stress, PLS), to bridge these cracks without fracturing, thereby providing the CMC with a high ultimate tensile strength (UTS).

In this way, the ceramic fiber reinforcements not only increase the composite structure's initial resistance to crack propagation, but also allow CMC to avoid abrupt brittle failure that is characteristic of monolithic ceramics. This behavior is distinct from the behavior of ceramic fibers in polymer matrix composites (PMC) and metal matrix composites (MMC), where the fibers typically fracture prior to the matrix due to the higher failure strain capabilities of these matrices.

• Toughening Mechanism by Particulate Materials

In this mechanism, one or more particles suspended in a ceramic matrix materials. The particles can be either metallic or nonmetallic, which classified as large particles phase and dispersion particles phase. Large particles have particles with a diameter of 1μm or more with volume fraction of (25-50%) or more of composite. The crack propagation is hinder by these particles result in enhancement in the fracture toughness.

On the other hand, the fracture toughness of ceramics are improved by dispersion small particles throughout the matrix with a diameter of 0.1μm and volume fraction of (1-15%) of the composite. In this type of toughening, the dispersion particles play a critical role in dislocation movement impedance that results in more resistance for crack initiation.

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