

The Detailed Study of Interphase Composition Affecting the Ceramic Matrix Composites: A Review

Karan Singh

Department of Mechanical Engineering, Shri Ram College of Engineering and Management Palwal (Haryana), India

Abstract

The fiber/matrix interface plays a significant role in determining the fracture behavior and mechanical properties of ceramic matrix composites. The critical driving force in the development of fiber reinforced ceramic composites has been the benefit of graceful failure and damage tolerance. In contrast to brittle ceramics, ceramic composites can survive local damage and inelastic deformation without catastrophic failure. The current research presents a review of interphase composition affecting the ceramic matrix composite.

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***Corresponding Author**

Email ID: karansrcem87@gmail.com

INTRODUCTION

The primary role of the fiber interface coating in Ceramic Matrix Composites (CMCs) is to provide a mechanism for crack deflection through debonding and frictional sliding. A successful fiber coating will stop or deflect micro cracks at the fiber matrix interface. Without debonding, the matrix cracks will cut through the ceramic fibers, rather than deflecting around the high-strength reinforcements. As further stress is applied and micro cracks begin combining and opening, the weakly bound fibers bridge the cracks and slide in the matrix, dissipating strain energy. Without controlled sliding of the fiber in the matrix, strain energy will not be dissipated and high stresses will form as the crack advances, leading to fiber fracture.^[1]

The interface coatings should be chemically and microstructurally stable at the desired operational conditions. Ideally, the coating will have no significant changes in chemical composition, phase

content or grain size at high temperatures or with repeated temperature cycling. The coating should be thermodynamically stable with the fiber substrate and the surrounding matrix, resisting solid-state reactions. Lastly, the coating should have resistance to oxidation, corrosion and steam and reduction attack. The critical role that the interface plays in strength and fracture toughness, any significant susceptibility of the coating to environmental attack across the range of performance conditions is a critical application barrier.

Interface coatings also serve as a secondary function in CMCs. Composite fabrication conditions and matrix precursors may be chemically aggressive with high temperatures and reactive chemical species, such as halides and free radicals. Ceramic fibers in CMCs may also be susceptible to environmental attack and solid-state matrix interactions in high temperature performance conditions. Fiber interface coatings can serve as reaction

and diffusion barriers in aggressive operations, again protecting the underlying fibers and/or intermediate coatings from chemical attack.^[2]

Direct application of the desired coating to the fiber before composite fabrication is the preferred coating method. The composition, morphology, and thickness of the coating can be easily controlled and tailored, independent of later composite fabrication conditions and heat treatments. The primary direct coating methods for ceramic fibers are chemical vapor deposition and liquid precursor's coatings. Both of these methods are advantageous for coating multifilament geometries, with good penetration into the interior of filament bundles.

INTERPHASE COMPOSITION

The detailed study of interphase composition presented as below:

Carbon

The initial success with ceramic matrix composites in the 1970s and 1980s was based on the use of carbon and boron nitride as interface coatings. Graphitic carbon interface coatings are deposited on fiber tows, cloth, or preforms using chemical vapor deposition/infiltration at relatively low temperatures of approximately 1100°C.^[3]

Ceramic composites with carbon interfaces have excellent room temperature mechanical properties. The graphite possesses an extremely low modulus along the c-axis; the interface is compliant and lessens the interfacial stresses that occur due to thermal expansion differences between the fiber and the matrix. The interfacial shear strength is dependent on the thickness of the carbon layer; thicker coatings produce lower interfacial shear strengths. The optimum thickness for the carbon interfaces in most composites is 0.15–0.24 microns. Carbon works well for most low temperature, non-corrosive

CFCC applications. However, carbon begins to oxidize at temperatures as low as 797°F (425°C), and oxidation is rapid at temperatures greater than 1562°F (850°C). Ceramic matrix composite is exposed to an oxidizing environment; oxidation begins with the attack/loss of carbon interfaces at exposed fiber ends. Carbon is removed along the entire fiber length resulting in an open channel at the fiber-matrix interface. The surfaces within the fiber and matrix will subsequently oxidize to form silica.^[4]

Boron Nitride

The poor oxidation resistance of carbon has led to the examination of alternative fiber coatings for use in Census Feature Class Codes (CFCCs). Hexagonal boron nitride possesses a crystallographic structure and mechanical properties similar to those of graphitic carbon. Most important is the significant improvement in oxidation resistance attained by using Boron Nitride (BN) coatings instead of carbon. Pyrolytic BN coatings exhibit good oxidation resistance up to temperatures as high as 2000°F.^[5] However, the presence of water vapor significantly accelerates the decomposition of BN over a wide temperature range. BN can be deposited on fiber tows, cloth, or preforms via chemical vapor deposition and infiltration techniques, usually from either NH₃, or hydrogen. Different BN processing temperatures can yield different crystallographic structures in the coating; deposition temperatures less than 1652°F (900°C) result in amorphous BN, intermediate temperatures produce fine-grained, polycrystalline, hexagonal BN, and high deposition temperatures, greater than 2372°F (1300°C), result in highly aligned, large-grain sized BN.^[6] The deposition temperature used will also depend on the fiber reinforcement selected. The BN crystalline structure has a profound effect on the stability of the BN coating in corrosive environments; amorphous coatings are inherently unstable and will decompose even at

relatively low temperatures, whereas the highly crystalline BN deposited at high temperatures is much more stable in environments containing oxygen and water vapor at elevated temperatures.^[7]

Oxide

Oxide fiber coatings offer an advantage of thermodynamic stability in the most frequent use environments anticipated for CFCCs – high temperature and oxidizing. It should be noted from the start that oxide fiber coatings are generally applied to oxide fibers and non-oxide coatings to non-oxide fibers.

The development of oxide fiber coatings has lagged that of non-oxide coatings such as boron nitride for a number of reasons:^[6]

1. Non-oxide fibers have been superior to oxide fibers and coating development has generally.
2. Advanced with improvements in fibers promising layered oxide compositions are not chemically compatible with available oxide fibers.
3. There has been difficulty identifying non-layered oxide fiber compositions which are stable with and weakly bonded to the available oxide fibers.
4. The greater chemical complexity of the oxide compositions, compared to non-oxide coatings such as carbon and boron nitride, has made coating deposition more difficult.

Non-layered Oxide interfaces

There has been recent progress in identifying non-layered oxides which appear chemically stable with available oxide fiber compositions, such as alumina and mullite, and which exhibit weak bonding to the fibers.

These oxide fiber coatings would generally be easier to incorporate into a composite than the layered oxides because no preferential alignment of the grains within

the coating would be necessary to achieve weak interfaces.^[5]

Layered Oxide Interfaces

Layered oxide fiber coatings have received a high level of interest. The use of this interfacial approach in real composites has been limited for a couple of reasons:^[3]

1. Temperatures greater than the capability of commercially available fibers have been required to form and texture the layered structures
2. The layered compounds are not chemically stable with the highest temperature capability fiber

Porous Matrices

Many organizations have developed a damage tolerant oxide-oxide CFCC by avoiding fiber coatings altogether. These composite systems have matrices with a large amount of residual porosity, often times exceeding 40%. These matrices are generally very weak and as a result, the composites usually exhibit damage tolerance through progressive and distributed damage under off-axis loading. Axial loading of these composites generally produces fairly linear stress-strain curves since their properties are fiber dominated. The ultimate strains-to-failure are representative of that expected from unreinforced fiber tows.^[4]

Porous Coatings

A logical extension of the porous matrix concept is to localize the porosity in a thin layer close to the fiber. The porosity in the coatings produced the desired debonding, but there was high sliding stress and limited fiber pull-out. It is suspected that the crack path in the porous interface was too rough and convoluted, producing the high sliding stresses. The tailoring of the grain size and porosity in the interface could reduce the sliding stress to acceptable levels.^[6]

CONCLUSION

The Composites have been used throughout history, i.e., straw in bricks, metal rod-reinforced concrete, and lightweight aerospace structures. Fiber reinforced polymer matrix composite materials are being introduced in ever-increasing quantities in military systems. The Interphase Composition plays an important role in affecting the Ceramic Matrix Composites as discussed in this research paper.

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