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A Brief Review On Ceramic Matrix Composites, It's Attributes and It's Utility In Future Generation Gas Turbine

Jitamitra Swain
B.E Student
Mechanical Engineering Department
Kirodimal Institute of Technology Raigarh (C.G.) INDIA

Kumar Gaurav
B.E Student
Mechanical Engineering Department
Kirodimal Institute of Technology Raigarh (C.G.) INDIA

Dheerendra Singh
B.E Student
Mechanical Engineering Department
Kirodimal Institute of Technology Raigarh (C.G.) INDIA

Prakash Kumar Sen
B.E Faculty
Mechanical Engineering Department
Kirodimal Institute of Technology Raigarh (C.G.) INDIA

Shailendra Kumar Bohidar
B.E Faculty
Mechanical Engineering Department
Kirodimal Institute of Technology Raigarh (C.G.) INDIA

Abstract

CMCs or Ceramic Matrix Composites 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, whereas carbon and carbon fibers can also be considered a ceramic material. CMCs were developed to overcome the problems associated with the conventional ceramics like alumina, silicon carbide, aluminum nitride etc – they fracture easily under mechanical or thermo-mechanical loads because of cracks initiated by small defects or scratches. Like in glass the crack resistance is very low. To increase the crack resistance or fracture toughness , particles (so-called mono crystalline whiskers or platelets) were embedded into the matrix.The present paper throws light on the different attributes of CMCs or Ceramic Matrix Composites, their mechanical properties and utility in future gas turbines.
Keywords: CMCs, Ceramic Matrix, Gas Turbine.

I. Introduction

Ceramic Matrix Composites(CMCs) are composites which came into emergence when ceramics which have great strength and properties fail under fracture or crack. The CMCs were developed to overcome the problem of fracture resistance. Generally normal ceramics, which are highly brittle in nature get fractured under fluctuating load if it contains cracks or flaws. Thus CMCs came into role which have reinforced substitute elements to increase resistance to fracture.

In general , Ceramic matrix composites (CMCs) have been developed to overcome the intrinsic brittleness and lack or mechanical reliability of monolithic ceramics, which are otherwise attractively known for their high stiffness and strength[1].

The reinforcing leads to enhancement of different properties like electrical conductivity, thermal expansion coefficient, hardness and thermal shock resistance[1][2]. The section below describes the different properties of CMCs.

II. Properties/Attributes of Ceramic Matrix Composites

The following mechanism helps to get high fracture toughness or crack resistance: under load the ceramic matrix cracks, like any ceramic material, at an elongation of about 0.05%. In CMCs the embedded fibers bridge these cracks [figure 1]. This mechanism works only when the matrix can slide along the fibers, which means that there must be a weak bond between the fibers and matrix. A strong bond would require a very high elongation capability of the fiber bridging the crack, and would result in a brittle fracture, as with conventional ceramics. As the name suggests these are highly brittle material composites.

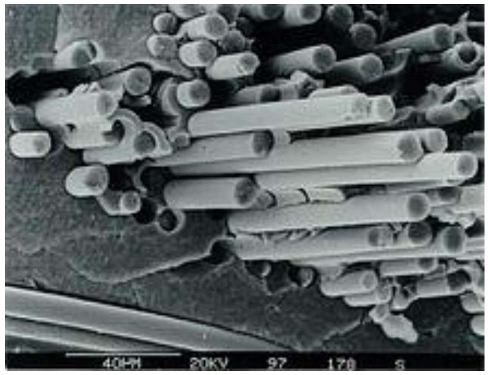

Fig. 1: ceramic matrix composites and SiSiC

Measurement of strength can be made by taking a specimen of basic ceramic with an initial notch and finding out the failure under different types of loads. The results can be plotted under a curve. The area under the curve gives the relative indication of the energy required to drive the crack tip through the sample. If compared to a sample of basic conventional SiSiC ceramic it can be inferred that:

(1) All the CMC materials which were tested need up to several orders of magnitude more energy to propagate the crack through the material.
(2) The force required for crack propagation varies between different types of CMCs.

The different basic properties are tabulated as below.

Table 1
Properties of different types of CMCs[3]

Types of material	*Al_2O_3/Al_2O_3*	*Al_2O_3*	*CVI-C/SiC*	*LPI-C/SiC*	*LSI-C/SiC*	*SiSiC*
Porosity(%)	*35*	*<1*	*12*	*12*	*3*	*<1*
Density(g/cm^3)	*2.1*	*3.9*	*2.1*	*1.9*	*1.9*	*3.1*
Tensile Strength(MPa)	*65*	*250*	*310*	*250*	*190*	*200*
Elongation(%)	*0.12*	*0.1*	*0.75*	*0.5*	*0.35*	*0.05*
Young's modulus(GPa)	*50*	*400*	*95*	*65*	*60*	*395*
Flexural Strength(MPa)	*80*	*450*	*475*	*500*	*300*	*400*

As stated earlier the reinforcement leads to enhancement of many other properties other than mechanical properties.

The fibers alignment in CMCs plays a vital role in deciding its physical as well as other properties. The properties also widely depend on the factor that whether we are using metal/non metal as matrix material. The most researched material which is used either as a matrix or as reinforcement is Carbon Nanotubes or commonly known as the CNTs which are tubular graphenes. Electrical and thermal conductivities are different in different orientation of matrix; i.e. different in parallel as well as vertical orientation. The conductivities are shown in table below.

Table 2
Thermal, electrical conductivities and expansion of different matrix composites

Material	*CVI-C/SiC*	*LPI-C/SiC*	*LSI-C/SiC*	*CVI-SiC/SiC*	*SiSiC*
Thermal conductivity(p)[W/m.K]	*15*	*11*	*21*	*18*	*>100*
Thermal conductivity(v)[W/m.K]	*7*	*5*	*15*	*10*	*>100*
Linear expansion(p)[10^{-6}·1/K]	*1.3*	*1.2*	*0*	*2.3*	*4*
Linear expansion(v)[10^{-6}·1/K]	*3*	*4*	*3*	*3*	*4*
Electrical resistivity(v)[Ω·cm]	*–*	*–*	*–*	*–*	*50*

Electrical resistivity(v)[Ω·cm]	*0.4*	*–*	*–*	*5*	*50*

Note:- "p" refers to parallel orientation and "v" refers to vertical orientation.

LSI material has the highest thermal conductivity because of its low porosity – an advantage for which it is being used in brake discs. These data are subject to scatter depending on details of the manufacturing processes.

Normal ceramics are very sensitive to thermal stress because of their high Young's modulus and low elongation capability. Temperature differences and low thermal conductivity create locally different elongations, which together with the high Young's modulus generate high stress.

III. CERAMIC MATRIX COMPOSITES AND THEIR UTILITY IN FUTURE GAS TURBINE

Since Ceramic Matrix Composites have low fracture toughness and don't have high brittleness as of conventional ceramics and also have high reliability in high temperature, these are used in areas where normal metals can't withstand the conditions.

In addition they are light weight and strong. So are preferred in aerospace division and in gas turbines.

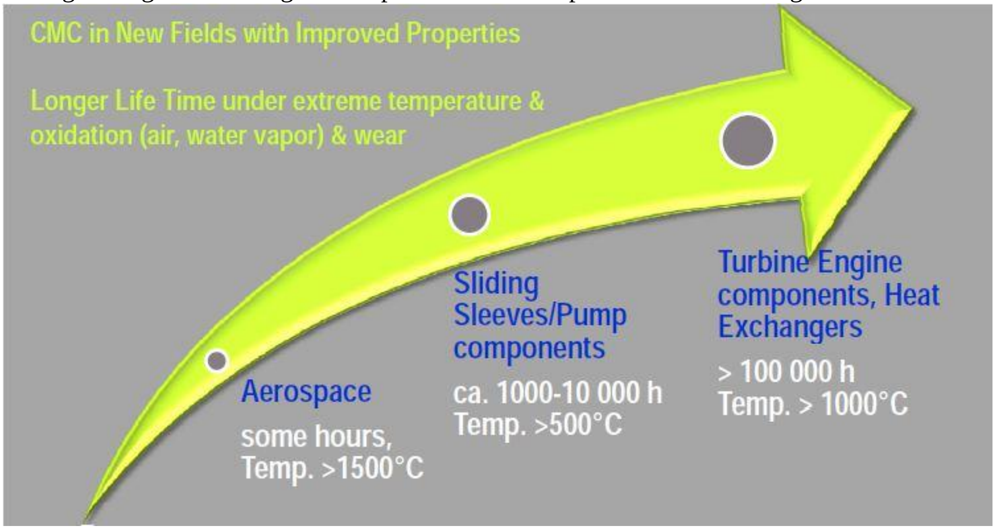

Fig. 2: CMCs in high utility divisions[4]

As it is already known that the gas turbine is a interest of light weight and high temperature resistant materials , CMCs come into role. The different parts of gas turbine such as the turbine blades, shrouds and vanes can be replaced with CMCs to meet the required heat resistance.

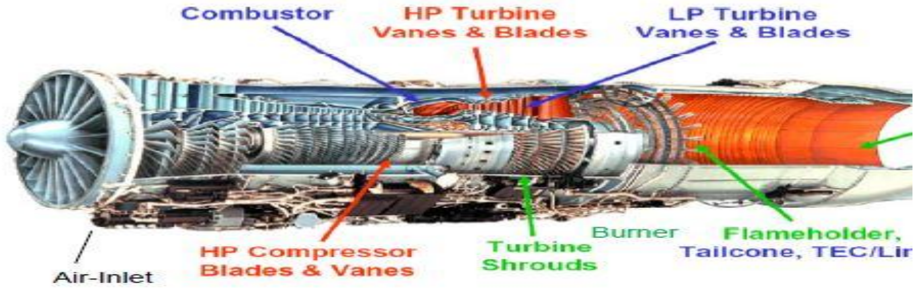

Fig. 3: Temperature zones of different parts of a gas turbine.

Due to its extreme properties it is also found in following applications [5]:

(1) Heat shield systems for space vehicles which are needed during the re-entry phase, where high temperatures, thermal shock conditions and heavy vibration loads take place.
(2) Components for high-temperature gas turbines such as combustion chambers and stator vanes and turbine blades.
(3) Components for burners and flame holders, and hot gas ducts, where the use of oxide CMCs has found its way.
(4) Brake disks and brake system components, which experience extreme thermal shock (greater than throwing a glowing part of any material into water).
(5) Components for slide bearings under heavy loads requiring high corrosion and wear resistance.

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