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AN OVERVIEW OF CERAMIC MATRIX COMPOSITES

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ABSTRACT- *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. 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. Moreover, ceramic matrix composites are widely used in several engineering applications such as in heat shield systems, gas turbines components such as 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. Ceramic materials possess high strength and modulus at elevated temperature. But their use as structural components is severely limited because of their brittleness. The continuous fiber rein forced ceramic-matrix composites (CMCs),by incorporating fibers in ceramic matrices, however, not only exploit their attractive high-temperature strength but also reduce the propensity for catastrophic failure. In this paper presents an over view and study on ceramic matrix composites of the role of oxidation in time-dependent response, properties of hexagonal boron nitride and fatigue behaviour of SiC composites.*

Keywords : *Ceramic matrix composites, Internal stress, Hexagonal boron nitride, Fatigue properties.*

1. INTRODUCTION

SiC-based Ceramic matrix composites (CMCs) are prime material candidates for the hot section in turbine engines due to their resilient behaviour in harsh environments. However, before this goal can be achieved, a few issues related to their performance have to be addressed[1-3]. Among these issues is the effect of oxidation of their constituents, under conditions of high temperature in an environment that contains oxygen and/or water vapour in an effort to prolong their ability to withstand such environment and enhance their mechanical reliability. A few researchers investigated the kinetics of the oxidation phenomenon for SiC-based composites and reported that some of the primary reactions included the oxidation of SiC, boron nitride (BN) and silicon nitride (Si_3N_4)[4]. Hexagonal Boron nitride (h-BN) is well known to be an important engineering ceramic. It has crystal structure analog of graphite. That is, within each layer, boron and nitrogen atoms are bound together by strong sp^2 covalent bonds, and the adjacent layers are integrated by weak vander waals forces [5–8]. This special crystal structure provides h-BN a series unique combination of properties, including low dielectric coefficient, low loss tangent, extremely high sublimation temperature of about 3000^oC(non-oxidizing atmosphere), excellent thermal shock resistance, and desirable machinability [9].However, there exist some problems that limit the application of h-BN material, such as low strength and poor sintering properties. As the strong covalence of B-N bond has a rather low self-diffusion coefficient, it is difficult to obtain dense materials even if they are sintered under high temperature (>2000^oC) or assisted by pressure. In tradition, only several kinds of oxides, such as SiO_2 and B_2O_3, are used as sintered additives, and the mixed powders are often sintered without pressure assistance. As a result, the h-BN ceramics show low relative density and poor properties, which constraint their application.

Carbon fiber reinforced SiC matrixes composites (C/SiC) have been extensively studied due to attractive properties, such as low density and high specific strength . Recently, C/SiC composites are promising materials for many applications, especially for aircraft engineer thermo-structural components [10–13]. However, oxidation of carbon fiber and interface pyrolytic carbon occurs much easily and limits long-term application for C/SiC composites in severe high temperature oxidizing environment [14–15].The C/SiC modified with boron bearing species, such as borosilicate glass,boron,boron carbide and Si-B-C ceramic, shows excellent self-healing property, especially with Si-B-C ceramic. Si-B-C ceramic can significantly improve the oxidation resistance of C/SiC composites in static air and wet oxygen environment. However, few investigations on fatigue behaviour of C/SiC composites modified only with Si-B-C ceramic have been conducted. Therefore, it is necessary to value the self healing property of C/SiC modified with Si-B-C ceramic under fatigue loading in static air.

2. METHODOLOGY

Micromechanics model :

In order to study the effect of oxidation on CMCs, it is important to account for the pre form geometry, distribution of porosity and crack density and have sufficient information on the in-situ properties of constituents[1-2]. In other words, a successful approach needs to either represent or attempt to simplify the following: 1) a repeat unit cell that represents the geometry of the fabric, fiber interface coating and matrix distribution, 2) knowledge of in-situ mechanical properties of constituents, 3) distribution of manufacturing porosity and their effect on mechanical properties, and 4) crack density as a function in pre form geometry and the stress within a unit cell. The models were developed to identify the unit cell of the fabric pre form (Fig. 1) and evaluate the elastic properties of the composite and its constituents, characterize the distribution of manufacturing porosity/defects and their impact on mechanical properties, and map the stress distribution in a unit cell and quantify its effect on crack density. In these models, an ideal geometric representation of the fabric is constructed by calculating the location of a set of spatial points (knots)that can identify the yarn center line path within the pre form space based on the fabric forming process in a typical textile machine. AB-spline function is used to approximate a smooth yarn center - line path relative to the knots . A yarn cross-section shape is swept along the center-line path and allowed to change dimensions based on availability of space between yarns and the thickness of the composite.

The boundary conditions of the unit cell, dictated by the assumptions of repeatability and continuity, are used to reduce the size of the stiffness matrix and a virtual work technique is used to calculate its stiffness matrix[3-4]. The shear lag theory is used to estimate crack density in sub cells subjected to tensile loads, where the cracks are assumed to only exist in the direction transverse to the load direction. Fibers are typically coated for protection against oxidation. Under mechanical and thermal loads, cracks develop in the composite exposing the fiber coating to oxidizing gases. Taking BN coating as an example, oxidation would typically start at the crack plane creating liquid B_2O_3 and exposing the fibers and their surrounding matrix to oxidation along both sides of the crack, as schematically shown in Fig. 2.

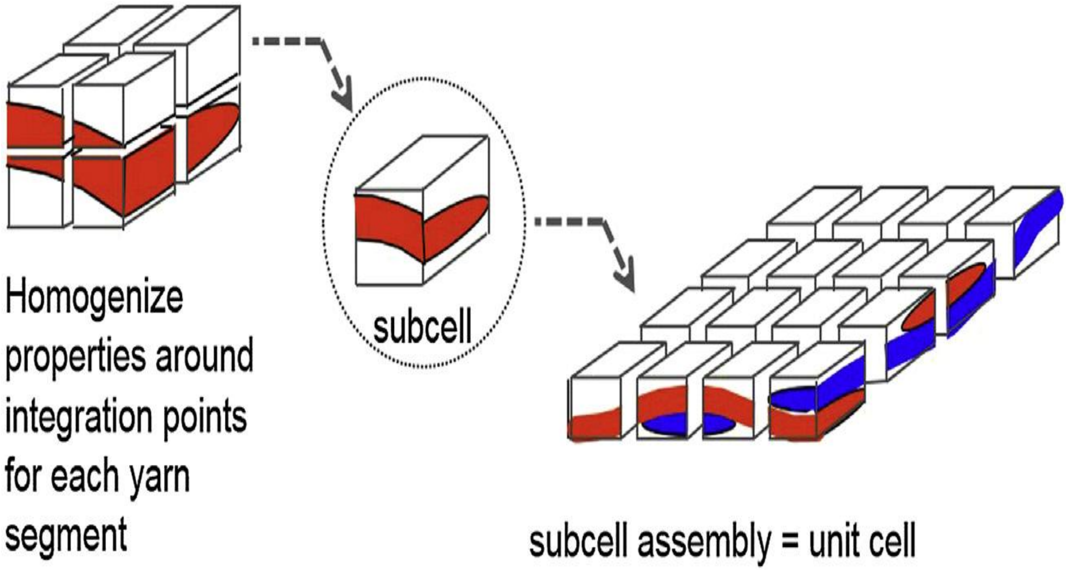

Fig.1. Model of discretized unit cell

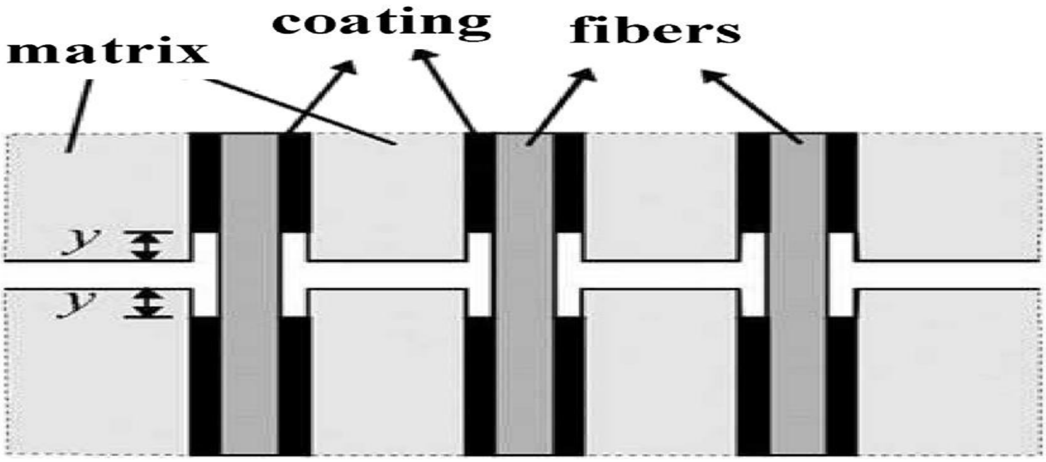

Fig.2. Recession distance y from the crack tip due to oxidation of fiber interface coating.

Mechanical Properties :

Typically, pure Hexagonal boron nitride (h-BN) ceramic shows relative lower mechanical properties due to the poor sintering activity and low density. Therefore, the sintering additives and secondary phases with strengthening effects are often used to improve its properties, and the relevant preparation process is developed to sintering h-BN matrix composite ceramics with various performances. The mechanical properties of h-BN matrix composite ceramics manufactured by different researchers. It can be seen that both compositions and sintering process can significantly influence the mechanical properties of h-BN matrix composite ceramics. In general, high temperature and high pressure can help atomic diffusion and reduce the gap [5-6]. As such, most of h-BN matrix composite ceramics are manufactured by hot pressing sintering method with various additives in order to improve their mechanical properties. During the sintering process, experimental parameters including temperature, pressure and soaking time have obviously effect on the performances of sintered samples[7-9]. A novel h-BN-MAS (magnesium aluminium silicate) composite ceramics with greatly improved mechanical properties prepared by hot-press sintering under relatively low temperature.

Fatigue Performance :

Two-dimensional preforms were fabricated from laminated weave carbon cloths (1K, T300, Toray Co., Japan). Pyrolytic carbon (PyC) interface with a thickness of 200nm was deposited on fiber using C_3H_6 precursor at 870 ^{o}C for 1 h at a reduced pressure of 5 kPa. Then, SiC matrix was infiltrated by low pressure chemical vapor infiltration (LPCVI) process for fabrication of C/SiC composites with density of about 1.7 g/cm^{3}and 1.9 g/cm^3 respectively[10-12]. Next, two layer of Si-B-C matrix and two layer of SiC matrix were infiltrated alternatively in sequence for specimen with density of 1.7 g/cm^3, then, three layers of SiC coating were deposited on specimen, which was marked as C/(SiC-SiBC)$_m$. In addition, SiC/Si-B-C/SiC coating was deposited on C/SiC composites with density of 1.9 g/cm^3 marked as SBS-C/SiC[13]. There were three samples tested at each specific temperature for C/(SiC-SiBC)$_m$ and SBS-C/SiC. As a comparison, three layers of SiC coating were deposited on C/SiC composites with density of 1.9 g/cm^3 named as C/SiC. Finally, the as-received composites were machined and polished into samples as shown in Fig.3.The fatigue tests were conducted in static air in electronic lasting creep relaxation testing machine at 300^{o}C, 550 ^{o}C, 750 ^{o}C,1000 ^{o}C and 1200 ^{o}C separately[14-15]. The tensile stress and loading frequency of the fatigue test were 60 ± 20 MPa and 0.5 Hz, respectively. Surface and cross-section morphologies of specimens were observed using scanning electron microscope.

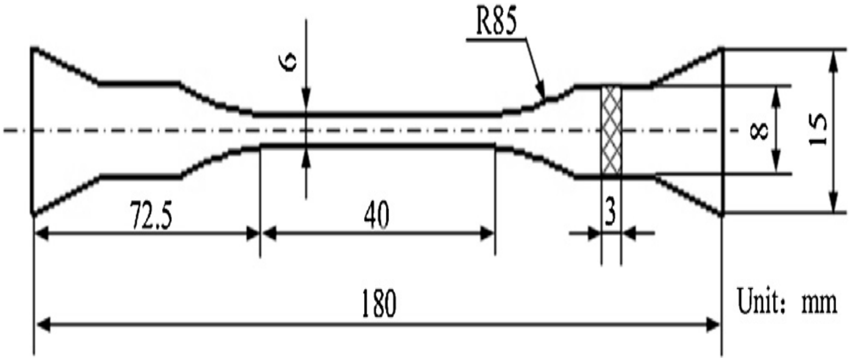

Fig. 3. Shape and dimension of fatigue specimen at high temperature

3. RESULTS AND DISCUSSION

Samples of the stress-strain curves obtained from tensile tests, and conducted at their respected testing temperatures, are observed. The lower modulus and strength as well as the high strain to failure of the SiC/SiNC, as compared to the MI SiC/SiC. MI SiC/SiC composite exhibited a more pronounced knee such as starts with the first departure from linearity and ends when another linear region dominates the curves than SiC/SiNC composite. The knee is attributed to the development and progress of cracks in the matrix which allows the environment to ingress into the composite. The range of the knee was evaluated to be between 47.6 and 155.4 MPa for the SiC/SiNC and 74.5 and 280.5 MPa for the MI SiC/SiC composite.

The AIN addition can also affect the evaluated temperature mechanical behaviours. For BN-SiO_2 composite ceramic, the relationship between bending load and deflection is approximately linear when the samples are analyzed under the temperature of 1300^{o}C, while the plastic deformation is observed at higher temperature, especially at 1500^{o}C. In contrast, in-situ h-BN–SiO_2–Sialon composite ceramics sintered by adding certain AIN have no plastic yield phenomenon even they are tested under1500^{o}C. Effect of AIN content on high temperature mechanical properties of h-BN–SiO_2–Sialon composite ceramics is shown in Fig.4. The flexural strength increased at first and then decreased with the increase of temperature, and the maximum values can be reached at 1300^{o}C. The increase of flexural strength is due to the internal stress relaxation and surface oxidation with forming thin glass layers.

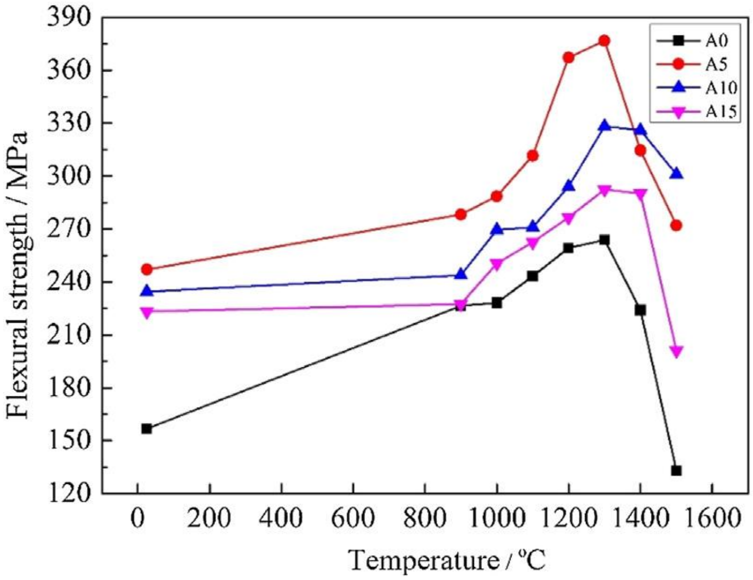

Fig. 4. Flexural strength versus temperature for h-BN–SiO_2–Sialon composite ceramics

The lifetime and fracture position of C/(SiC-SiBC)$_m$ and SBS-C/SiC at different temperatures in air. In order to clearly illustrate these results, fatigue lifetime diagram in relation-ship with temperature for different specimens is shown in Fig.5. It can be seen that the average fatigue lifetime of C/(SiC-SiBC)$_m$ at all test temperatures are longer than those of C/SiC. C/SiC and C/(SiC-SiBC)$_m$ do not break after fatigue at 300 ^{o}C for 100 h and the residual tensile strengths are 162 MPa and 201 MPa, respectively, indicating that fatigue leads to degradation of the tensile strength compared to original sample (277 MPa). The lifetimes of C/SiC and C/(SiC-SiBC)$_m$ after fatigue at 550 ^{o}C are 14 h and 21 h, respectively, which both decrease significantly, and samples break at the center zone loading the most; when the fatigue temperature is up to750^{o}C, the lifetimes of both materials further decrease and the life-time of C/(SiC-SiBC)$_m$ reaches the minimum (around 6.6 h). When the temperature rises to 1000^{o}C, the lifetime of C/SiC reaches the minimum (0.5 h) while the lifetime of C/(SiC-SiBC)$_m$ increases to 9 h, and samples break at their center and top zone. Eventually, with temperature further rising to 1200^{o}C, the lifetimes of both specimens increase, meanwhile samples break at both ends, not at the center. When the test temperature is under 1000^{o}C, the temperature difference between the center and both ends of samples is small, so there is no influence on the test. However, the temperature of the both ends of sample is 200–300^{o}C lower than that of the center as the test temperature rises to 1000^{o}C, therefore, glass phase formed by oxidation of Si- B-C ceramic at the both ends is deficient to fill cracks timely due to the small oxidation rate at lower temperature, resulting in the fracture at the both ends of samples and the integrity at the center of samples.

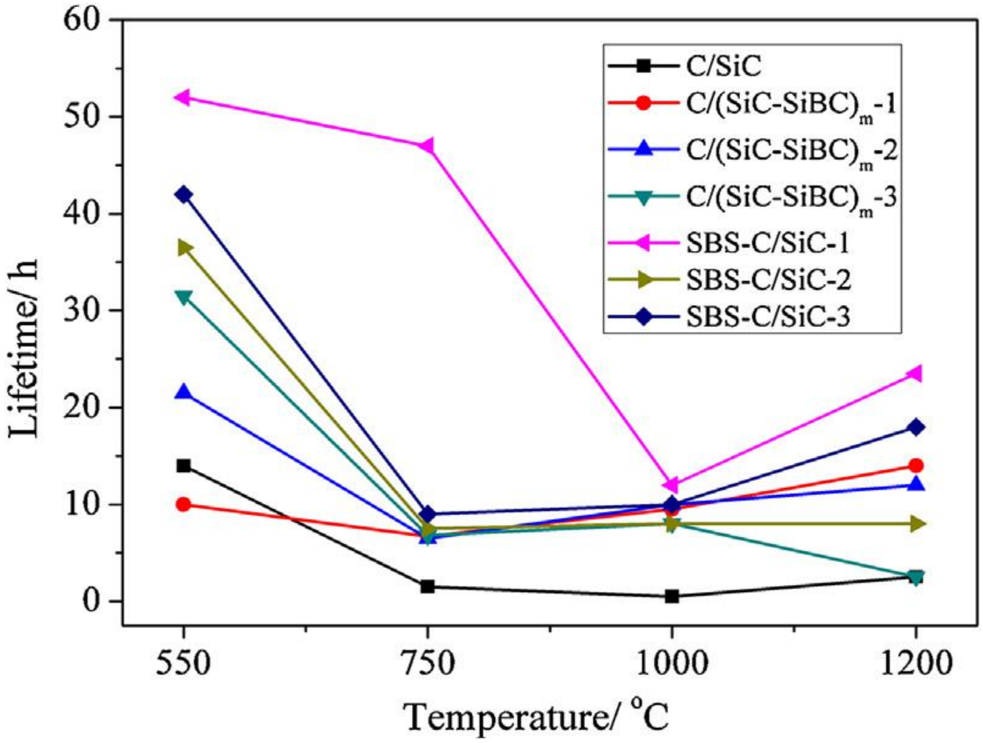

Fig. 5. Relationship between fatigue temperature and fatigue lifetime for different specimens

4. CONCLUSIONS

A numerical model was constructed to account for the effect of strain accumulation due to oxidation in CMCs. Model results showed that strain accumulation due to oxidation in SiC/SiNC composite was more rapid than in MI SiC/SiC composite at similar stress levels. It also showed that it is highly affected by the fiber architecture, the thickness of the protective fiber coating layer as well as the absolute values of the linear and parabolic oxidation rate constants and their ratio to one another. Model results for strain accumulation due to oxidation was compared to time-dependent strain accumulation data obtained from dwell fatigue experiments for both composite systems. Comparison showed that the primary time-dependent strain accumulation zone witnessed in dwell fatigue experiments was dominated by creep strain and that strain due to oxidation started to be effective only after the end of that zone. The rate of strain accumulation due to oxidation was very high as compared to the time-dependent strain accumulation rate in the steady- state zone and can be the reason for a tertiary zone and composite failure.

The Hexagonal boron nitride (h-BN) matrix composite ceramics have been used as key materials in many fields and great endeavour has been made to improve the sintering process in order to optimize their performance. Now that the most of existing materials are manufactured by hot-press sintering, their performances need to be further improved by optimizing the parameters during the treatment. It should be noted that some new materials that belong to boron nitride family showing new morphologies have been recently developed and gained extensively research interest, such as BN fiber, BN whisker, BN nanowire, BN nanotube, and BN nanosheet, which have similar structure and outstanding performances, show great potential for perfection the properties of h-BN matrix composite ceramics.

Borosilicate glass formed from Si-B-C ceramic can seal the cracks in composites and prevent oxygen diffusing into composites. The fatigue lifetime of C/SiC modified with Si-B-C ceramic have been improved obviously. Si-B-C ceramic in SBS-C/SiC oxidizes more easily with oxygen diffusing from cracks in composites and forms more borosilicate glass than that in C/(SiC-SiBC)$_m$. Quantity and formation rate of borosilicate glass formed from Si-B-C ceramic directly affect crack-healing and fatigue lifetime of specimens. Fatigue life time of specimens modified with Si-B-C coating is superior to that of Si-B-C matrix.

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