

# Chapter 18

## C/C–ZrB<sub>2</sub>–ZrC–SiC Composite Derived from Polymeric Precursor Infiltration and Pyrolysis Part 2: Mechanical and Ablation Properties

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### ABSTRACT

*Mechanical and ablation properties of the 2D C/C–ZrB<sub>2</sub>–ZrC–SiC composites with a fiber volume fraction of 17.6%, fabricated by infiltration and co-pyrolysis of blended polymeric precursors, were studied in this Part II. Flexural strength and fracture toughness of the composites were found to be influenced strongly by the thickness of the deposited pyrolytic carbon interphase, a composite with the pyrolytic carbon volume fraction of 22.3% exhibits improved bending strength and fracture toughness of 127.9 MPa and 6.23 MPa·m<sup>1/2</sup>, respectively. The pseudo-plastic strain to failure of the composite is ascribed to sliding of the interphase and pulling out of carbon fibers from the brittle ceramics matrix. Ablation properties of the composite were investigated with a plasma torch and arc-heated wind tunnel tests at temperatures above 1800–2200°C. The composite exhibits very low ablation rates of 0.18×10<sup>−3</sup> mm/s at 1800°C and 0.37×10<sup>−3</sup> mm/s at 2000°C in the plasma torch after 1000s testing, as compared to a similar rate of 0.30×10<sup>−3</sup> mm/s in the wind tunnel at 1900°C after 600s testing. Ablation rates increase with increasing of temperatures from 1800 to 2200°C. The maximum ablation rate is only 1.67×10<sup>−3</sup> mm/s in a plasma torch at 2200°C for 1000s, decreased by 71.0% as compared with the C/C–SiC composite with the same*

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fiber and interphase contents. The 2D C/C-ZrB<sub>2</sub>-ZrC-SiC composite simultaneously showed excellent thermal shock resistance, on account of no cracks on the surface and breakage of the material being detected after these abrupt temperature increasing and long time ablations. The heating-up rate at the center of the composite specimen was found as high as above 30K/s in the plasma torch tests. Excellent ablation and thermal shock resistances of the composite can be attributed to its architecture of carbon fiber and interphase, as well as its matrix microstructures characterized by nano sized dispersions of ZrB<sub>2</sub>-ZrC-SiC phases inherent formed by co-pyrolysis of three polymeric precursors. These meso- and microstructures make the composites possess very small and steady coefficients of thermal expansion (CTE) around  $1.5\sim 2.5\times 10^{-6}/\text{K}$  and high thermal conductivities around 10~14 W/mK (which increases with increasing of temperature) from room temperature to 1300°C, respectively. Surface products and cross sectional morphologies of the composite after the ablation tests were also investigated using SEM and XRD, it was found that a homogeneous distributed and continuous glass layer composing of ZrO<sub>2</sub>-SiO<sub>2</sub> with zirconia as a skeleton was in-situ formed. These special features of coating benefits from the merits of matrix microstructures, and inhibits the inward diffusion of oxygen and protects the composite from further oxidation and spalled off by strong gas fluid.

## 1. INTRODUCTION

In the previous chapter, preparation process and microstructure investigation of a novel C/C-ZrB<sub>2</sub>-ZrC-SiC composite were reported, in which polymeric precursors of ZrB<sub>2</sub>-ZrC were used to fabricate an ultra-high temperature ceramics (UHTCs) matrix for the first time but with the traditional polymeric precursor infiltration and pyrolysis (PIP) technique. The formed ZrB<sub>2</sub>-ZrC-SiC complex matrix exhibits homogeneous dispersion of nano-sized ZrB<sub>2</sub> and ZrC particles in continuous SiC ceramic all with particle dimensions less than 200 nm. This kind of composite should exhibit improved anti-oxidation and ablation resistance properties at ultra-high temperatures above 1800°C, especially undergoing hypersonic combustion flame corrosion and spallation<sup>[1]</sup>.

In this chapter, the ablation behavior and thermo-mechanical properties of the prepared composites are therefore studied. Ablation properties were investigated using two ground simulated technologies, i.e. the plasma torch heating technique and arc-heated wind tunnel test, both methods are usually used to evaluate ultra high temperature ablation properties of materials<sup>[2-6]</sup>. The flexural strength and fracture toughness of

the fabricated C/C-ZrB<sub>2</sub>-ZrC-SiC composites were measured by three-point-bending and single-edge-notched-beam (SENB) test, respectively.

Validating the anti-ablation capability of a novel material is always important to accomplish its applications. Ablation behavior of a material and its component parts can be investigated by flight experiments or ground based simulation experiments<sup>[3,5]</sup>. Ballistic flight experiments have been used to test UHTCs and composite components aimed to obtain and evaluate their global mechanical and integrated ablation properties. Ground based simulation experiments were used more widely because of its versatility and low cost. A lot of technologies have been used for decades to test the ablation properties of C/C or C/SiC composites as well as UHTCs, such as hypersonic wind tunnel, high-power laser beam, arc-jet flame, plasma and oxyacetylene torch, which can provide experimental conditions of high enthalpy and ultra high temperatures. A hypersonic wind tunnel can additionally provide strong gas flow with various static and dynamic pressures, to simulate the real environments of flying for those materials used at ultra-high temperature and undergoing strong fluid-solid surface interactions. Therefore, a wind tunnel experiment driven by combustion or arc-jet

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