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Ablation resistance of ZrB_2–SiC coating prepared by supersonic atmosphere plasma spraying for SiC-coated carbon/carbon composites

Yulei Zhang*, Zhixiong Hu, Hejun Li, Jincui Ren

State Key Laboratory of Solidification Processing, C/C Composites Research Center, Northwestern Polytechnical University, Xi'an 710072, PR China

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Abstract

To improve the ablation resistance of carbon/carbon (C/C) composites, ZrB_2–SiC coating was prepared on the surface of SiC-coated C/C composites by supersonic atmosphere plasma spraying. Ablation resistance of the coating was investigated by oxyacetylene torch under different heat flux. Results show that the multilayer coating is dense and its thickness is about 60 μm. The mass and linear ablation rates of the coated C/C composites are 0.4×10^{-3} g/s and 0.6 μm/s after ablation for 60 s under the heat flux of 2400 kW/m^2. However, the coating is failure after ablation for 60 s under the heat flux of 4200 kW/m^2. The good ablation resistance of the coating under the heat flux of 2400 kW/m^2 is mainly attributed to the formation of a dense ZrO_2–SiO_2 scale, which could act as thermal barrier and reduce inward diffusion of oxygen.

Keywords: Carbon/carbon composites; Coating; Supersonic atmosphere plasma spraying; Ablation

1. Introduction

Carbon/carbon (C/C) composites have been considered as one of the most promising materials as thermal–structural components at high temperature due to their good properties, such as low density, high strength and modulus of elasticity, good creep and thermal shock resistance [1]. However, C/C composites are rapidly oxidized above 673 K, which becomes a fatal weakness for its applications [2–4]. Up to now, many ceramic coatings, such as $MoSi_2$ coating [5], Y_2SiO_5/SiC coating [6], and $ZrSiO_4$/SiC coating [7] have been developed to improve the oxidation resistance of C/C composites, and they exhibit good oxidation protection ability at 1773–1873 K. But they cannot meet the application requirements of higher temperature (above 2000 K) and high-pressure gas flow [8]. So it is necessary to improve ablation resistance of C/C composites in this environment.

In previous research, many ultra-high temperature ceramics (UHTC) (such as HfB_2, ZrC and TaC) have been used as anti-ablation coatings for C/C composites [9–12]. As one of the UHTC, ZrB_2 has attracted much attention due to its good properties, such as high melting point (3313 K), high thermal conductivity, good chemical and physical stability at high temperature [13–15]. As is well known, SiC ceramic is widely used as an additive into ZrB_2 ceramic to improve its oxidation resistance [16–20]. ZrB_2 with 20–30 vol% SiC composites exhibits good ablation property at high temperature [21,22]. Therefore, ZrB_2–SiC ceramic can serve as coating for C/C composites. Currently, many methods have been developed to prepare the ZrB_2–SiC coating. Zou et al. [8] prepared ZrB_2–SiC coating by pack cementation, however, grain coarsening and lower content of ZrB_2 are its shortcomings. Zhou et al. [23] prepared ZrB_2–SiC coating through vapor silicon infiltration (VSI) process. But VSI process has to be repeated several times to ensure thickness of the coating, which is time-consuming and undesirable. Li et al. [24] prepared the ZrB_2–SiC coating for C/ZrB_2–SiC composites by slurry method. However, the weak bonding strength between coating and matrix restricts the ablation resistance of ZrB_2–SiC coating. Supersonic atmosphere plasma spraying (SAPS) has been widely used to prepare the UHTC coatings [5,21]. The temperature of plasma arc is about 10,000 K

*Corresponding author. Tel.: +86 29 88491384; fax: +86 29 88492624.
E-mail address: Zhangyulei@nwpu.edu.cn (Y. Zhang).

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and velocity of particle is up to 600 m/s [5,7,11]. In addition, the deposition of high-speed particles on the substrate can generate great jet impact force, which is beneficial to the formation of dense coating with good bonding strength [11].

Table 1
Details of the spraying parameters for ZrB_2–SiC coating.

Content	Parameters
Spraying current (A)	350–400
Spraying voltage (V)	120–150
Primary gas Ar (L/min)	75
Carrier gas Ar (L/min)	10
Second gas H_2 (L/min)	5
Powder feed rate (g/min)	30
Spraying distance (mm)	100
Nozzle diameter (mm)	5.5

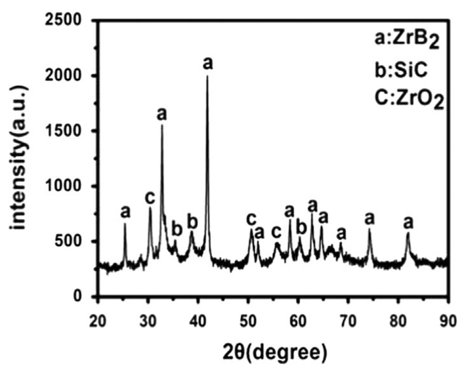

Fig. 1. XRD pattern of ZrB_2–SiC coating prepared by SAPS.

In the present work, ZrB_2–SiC coating was prepared by SAPS. In order to relieve the mismatch of the coefficient of thermal expansion (CTE) between ZrB_2–SiC coating and C/C composites, a SiC inner layer acting as bonding layer was first prepared on C/C composites. The ablation resistance of the coated composites was investigated by oxyacetylene torch test. The phase compositions, microstructures and failure mechanism of the ZrB_2–SiC coating were also investigated.

2. Experimental

2.1. Preparation of ZrB_2–SiC coating for SiC coated C/C composites

The substrates (∅ 30 × 10 mm) were cut from bulk 2D C/C composites with a density of about 1700 kg/m^3. Then the specimens were cleaned with ethanol and dried at 373 K for 2 h. The SiC inner layer was prepared by pack cementation and the details have been reported in Ref [25]. The ZrB_2–SiC coating was prepared on the SiC-coated C/C composites by SAPS in air. The mixture of 75 vol% ZrB_2 and 25 vol% SiC powders was selected as starting material. Before spraying process, the mixture particles were agglomerated by spray dryer to ensure flowability of particles when transported from powder feeder to injector. The spraying powders were obtained by agglomerating the slurry, which was composed of distilled water (49 wt%), polymeric binder (2 wt%), and mixture particles (49 wt%). The spraying system consists of plasma torch,

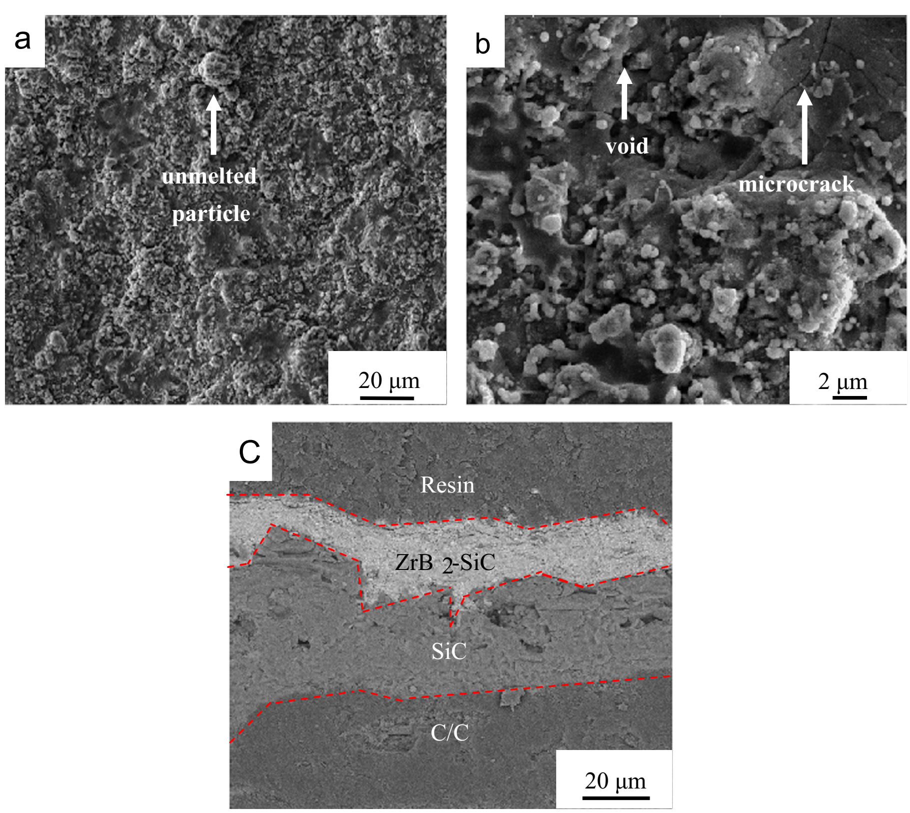

Fig. 2. Surface SEM images and cross-section backscatter micrograph of coated C/C composites: (a) low magnification; (b) high magnification of (a); (c) cross-section image.