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Microstructure and property of SiC coating for carbon materials

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Abstract

SiC coating has been developed on four kinds of carbon substrates using a slurry-sintering method. The relationship between the microstructure and property of SiC coating and carbon substrates was investigated experimentally and theoretically. It was found that the pore radius of carbon substrates has marked effect on the microstructure and property of SiC coating. SiC gradient coating which is beneficial to improve the oxidation resistance for carbon materials, is expected to form on the surface of carbon substrate with the pore radius mainly over the range of 100–500 nm.

Keywords: SiC coating; Oxidation; Pore radius; Carbon materials

1. Introduction

Carbon materials possess excellent thermal conductivity, stability under high temperature and resistance against irradiation, so they have been received much attention as plasma facing components (PFCs) in current Tokamak facilities [1–3]. But a high reactivity to oxygen or hydrogen at high temperature has been known as a major drawback of the carbon materials [4–5]. One of the ways to prevent these materials from eroding through formation of hydrogen or carbon oxide is to cover the surface with a protective layer.

With low atomic number (low Z) constituents, SiC ceramic has a series of advantages for use in a fusion reactor, such as good high temperature properties, corrosion resistance, low density, and especially its environmentally benign property for low induced radioactivity after neutron irradiation [6,7], and it will be also excellent for fusion applications. However, the mismatch of the coefficient of the thermal expansion (CTE) between SiC and carbon materials causes many cracks in the SiC coating during heat loading and unloading. In recent years, a concept of compositionally graded material is useful for reducing

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such a mismatch of the CTE, and for moderating the thermal stress distribution. Therefore, an introduction of functionally graded SiC layer on the surface of carbon materials has been widely studied using various methods such as pack cementation [8], chemical vapor decomposition (CVD)[9], laser-induced chemical decomposition (LICD) and slurry-sintering [10]. Among these methods, slurry-sintering technique has usually been used because it can provide for a graded distribution of elements at the interface between SiC coating and carbon substrates in the process of the infiltration of liquid Si into pores of the substrates [10]. However, in this technique, microstructure and properties of SiC coating for different carbon materials might be quite different, and few researches have reported the relationship between carbon materials and microstructure and properties of SiC coating in detail.

In this study, SiC coating was prepared on four kinds of carbon substrates using slurry-sintering method. Carbon substrates were dipped into the slurry containing Si powder to obtain Si pre-coatings, and then sintered at 1500 °C. Microstructure and anti-oxidation ability of the as-received specimens were also investigated.

2. Experiment

The characteristics of four kinds of carbon substrates were summarized in Table 1. 1# graphite was the under construction at author' institute by using hot-pressing method. He Nan Carbon Corporation provided 2# graphite. 3# was a type of anode graphite provided by Jilin Carbon Corporation. 4# was the C/C composites (plane disk brakes made in Xi'an, China). In addition, the distribution of the pore radius of four types of carbon substrates was measured using Quantachrome Autoscan Mercury Porosimetry and shown in Table 2. Four types of carbon materials were cut into small specimens with a size of 15 mm × 15 mm × 30 mm. Before coating, the specimens were hand-polished, then ultrasonically cleaned with distilled water and dried at 120 °C. In the preparation of Si slurry, high purity Si powder with average sizes of 7 μm was weighed and blended with water and polyvinyl-acetone (PVA) binder in a ball mill for about 1 h. The solid-to-liquid ratio of the slurry was adjusted to produce a viscosity suitable for the application of slurry on the specimens. The samples were dipped into the resulting slurry. After drying, the sintering of as-coated specimens was performed at 1500 °C for 2 h in a vacuum furnace.

Table 2
The distribution of pore radius of four types of carbon materials

Pore radius (nm)	(%) Volume in interval of carbon materials			
	1#	2#	3#	4#
2–5	10.23	4.64	2.43	3.86
5–10	12.23	2.53	4.86	2.93
10–50	50.48	14.3	9.40	13.2
50–100	9.03	8.68	11.40	7.68
100–500	11.35	48.00	2.71	50.20
500–1000	3.82	17.6	10.31	15.4
1000–4000		2.71	56.80	3.78
Total	97.14	98.46	97.91	97.05

The isothermal oxidation tests of the as-received samples were performed at 1200 °C in a corundum tube electrical furnace in air. Cyclic thermal shock tests were conducted in air environment as follows: Firstly the electrical furnace was heated to a specified temperature (1020 °C), secondly the specimens were placed into the furnace and hold this temperature for 5 min; and lastly the specimens were quenched into water of 20 °C. After each thermal shock test, the specimens were isothermally heated at 1200 °C in air for 1 h, then weighed at room temperature. The above procedure was repeated.

The morphology and crystalline structure of the coating were analyzed by scanning electron microscopy (SEM) and X-ray diffraction (XRD).

Table 1
Physical and mechanical properties of the substrate materials

Substrate materials	Density (g/cm^3)	Open porosity (%)	Compressive strength (MPa)
1#	1.98	12.6	54
2#	1.78	15.6	46
3#	1.60	18.8	32
4#	1.76	16.2	126