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Erosion resistant composite coating on rigid carbon fiber felt

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Abstract

Rigid carbon fiber felt (RCFF) was surface modified with a composite coating via a two-step technique of pasting and chemical vapor deposition. Scanning electron microscopy and X-ray diffraction were performed to analyze the microstructure of the substrate and the composite coating. The effect of the deposition time on solid particle erosion properties of RCFF modified by a composite coating was investigated. The pyrolytic carbon can decrease the surface porosity of a carbon fiber cloth, resulting in a dense composite. Compared with the substrate, the composite coating exhibited good erosion resistance and reduced the mass loss of the substrate by a factor of 19. The strengthening mechanism was discussed in this paper, and crack propagation along the interface between a carbon fiber and pyrolytic carbon sheath was found to occur; the crack propagation is an important factor for improving erosion resistance.

Keywords: Solid particle erosion; Composite coating; Rigid carbon fiber felt; Erosion behaviors

1. Introduction

Rigid carbon fiber felt (RCFF) is a special class of low-density, highly porous carbon/carbon composites. These composites are produced from polyacrylonitrile (PAN)-based carbon fiber felt through impregnation, solidification, and carbonization. For these materials, the majority of the volume (70–90%) consists of interconnected pores that originated from the oriented arrangement of fibers. A high porosity content and high fiber orientation result in a low thermal conductivity that is perpendicular to the fiber layer planes. In addition, carbon fiber felt has the highest thermal stability in vacuum and inert atmosphere at a high temperature among all types of fibrous felts. Therefore, RCFF has been utilized as thermal insulation in vacuum and inert gas furnaces, which should be cooled by inert gas at temperatures of up to 2800 °C. When a gas quench was employed in metal heat treatment, particulate matter was entrained in the gas flow and impinged on the RCFF insulation, resulting in erosion.

To protect RCFF against erosion, there has been strong interest in developing protective coatings for these materials [1–5]. Baxter et al. studied several carbon-based coatings on carbon bonded carbon composites [6]. The results show that the coatings improved the erosion resistance of carbon bonded carbon composites to varying extents. Among all of the coatings, the G3470 C/C composite coating showed the best erosion resistance, but the microstructure and erosion behaviors of the coating have not been investigated.

In this work, a composite coating, with a bonding layer and carbon fiber cloth/pyrolytic carbon composite layer (C/C layer), was prepared via a combined pasting and the chemical vapor deposition (CVD) method. The microstructure and solid particle erosion performance of the composite coating were examined. The erodent surface features of the coating were analyzed using scanning electron microscopy (SEM), and erosion mechanisms were investigated.

2. Experimental procedures

2.1. Materials

A standard commercial RCFF (density 0.20 Mg m^{-3}) manufactured by INV Ltd. (China) was used as substrate. A

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2-D woven carbon fiber cloth produced from a PAN precursor with a thickness of approximately 400 μm was used as the raw coating material. First, the carbon fiber cloth was prepared using a pasting method with an adhesive including phenolic resin, graphite powder, and alcohol (weight ratio of 1:1:2). Heat treatments at 100 ℃ for 24 h for resin curing and carbonization at 1200 ℃ for 2 h were used. The samples were hand-polished using 320 grit SiC paper and then ultrasonically cleaned with distilled water. Subsequently, the carbon fiber cloth was densified via CVD through the thermal decomposition of natural gas, as the carbon precursor (the main composition is methane), and argon, as the dilution gas. The deposition occurred at 1100 °C, with a flow rate of Ar of 250 ml min^{-1} and a flow rate of natural gas of 750 ml min^{-1} while the system was maintained at a pressure of 5 kPa. Composite coatings with different densities were obtained for different CVD treatment times (1, 3, 5, and 8 h). The deposition conditions are listed in Table 1.

Table 1
CVD process conditions.

Coating temperature/°C	Total gas pressure/kPa	Natural gas flow/L min^{-1}	Ar gas flow/ L min^{-1}	Coating time/h
1100	5	750	250	1, 3, 5, 8

2.2. Structural characterization

The morphology and composition of the composite coatings were examined using SEM (TM3030Plus) and X-ray diffraction (XRD; SHIMADZU XRD-6000), respectively.

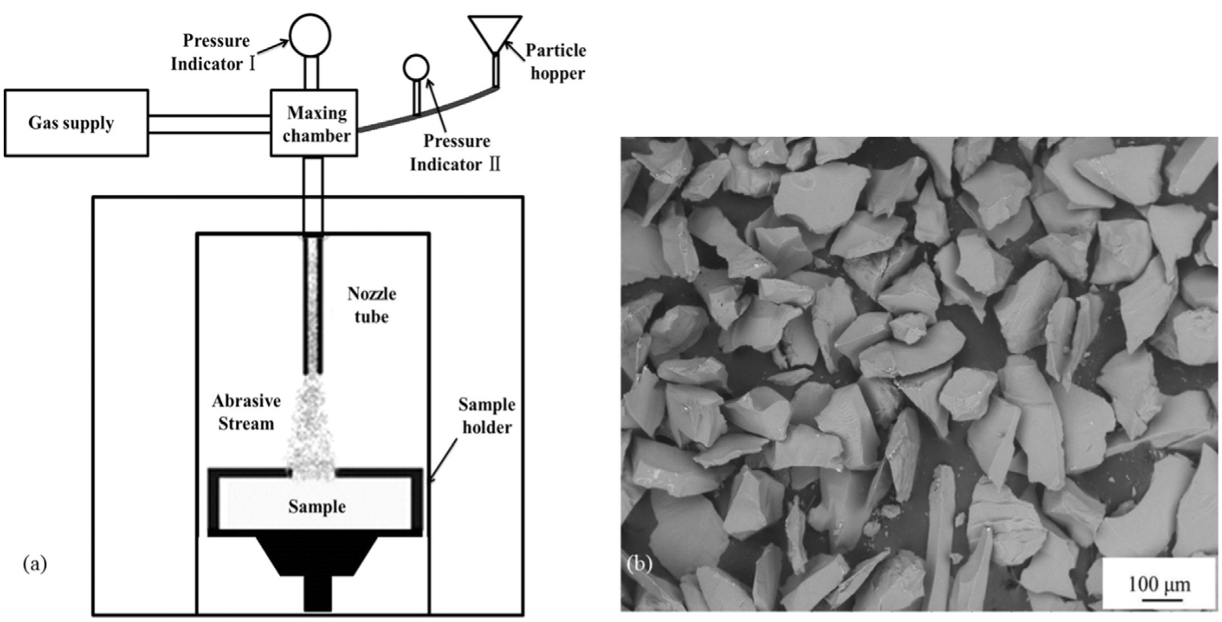

Fig. 1. (a) Diagram of the apparatus used for erosion testing; (b) micrograph of alumina abrasives used for erosion testing.

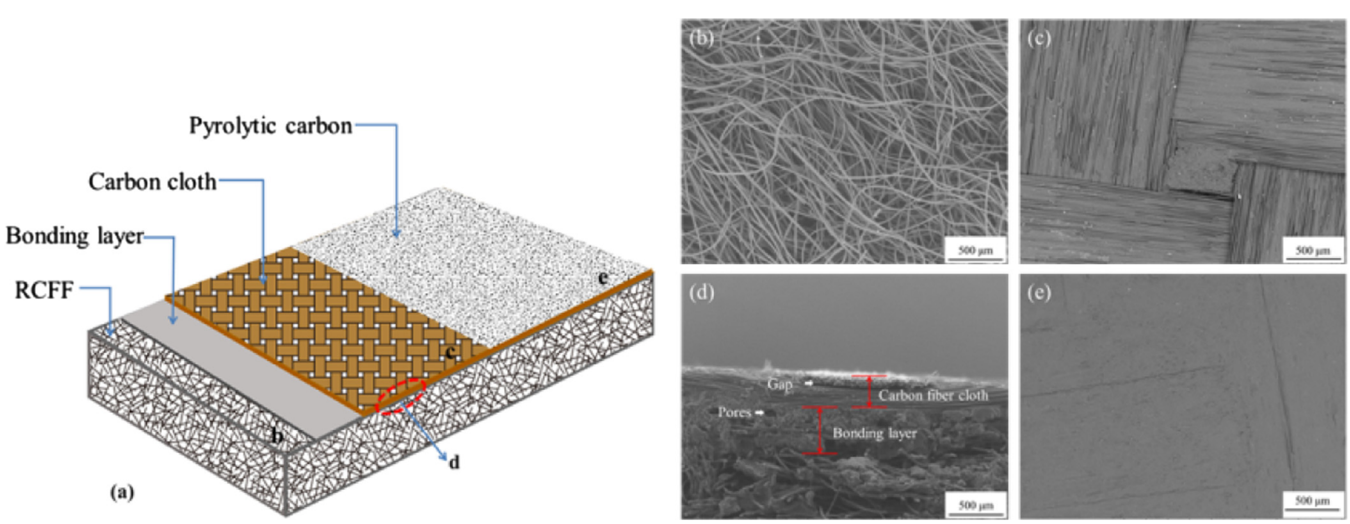

Fig. 2. The schematic and microstructure of composite coating. (a) The schematic of composite coating; (b) the surface of RCFF substrate; (c) the surface of carbon fiber cloth coating; (d) the cross-section microstructure of bonding carbon fiber cloth coating; (e) the surface of composite coating.