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Erosion behaviour of B_4C-based ceramic composites

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Abstract

In this paper, TiO_2 was introduced into boron carbide and B_4C-based ceramic composites were obtained by uniaxial hot pressing. The mechanical properties, relative density and erosion behaviour of B_4C-based ceramic composites were investigated. X-ray analysis showed that the fabricated composites were composed of B_4C, TiB_2 and C phases. SEM technique was employed to observe the original polished surfaces and the eroded surfaces of B_4C-based ceramic composites. The effect of impingement angle, impact velocity of SiC erodent particle, relative density and phase ratio on the erosion rate of B_4C-based ceramic composites was determined. It was found that the erosion rate of B_4C-based ceramic composites increased with increasing of impingement angle and erodent particle velocity. The relative density and phase ratio influenced the erosion rate of B_4C-based ceramic composites significantly by influencing their mechanical properties.

Keywords: A. Hot pressing; B_4C; TiB_2; Erosion behaviour; Microstructures

1. Introduction

Erosion is a serious problem in many engineering systems, such as jet turbines, pipelines and valves used in slurry transportation, cyclone generators and fluidized bed sand boilers [1–3]. Ceramic matrix composites possess attractive properties, these include high hardness, low density, good chemical stability, high corrosion resistance and temperature tolerance, making them useful for advanced structural and tribological applications [4–6]. Boron carbide (B_4C) has excellent hardness, a high melting point, low specific weight and great resistance to chemical agents at room temperature, so it is currently used in high technology industries for such applications as blasting nozzles, light weight armors and high temperature thermoelectric conversion. Abrasive air-jet nozzles made of boron carbide of high relative density provides a long life owing to excellent wear resistance compared with other nozzle materials [7–8].

Although there is considerable interesting on the erosion wear of ceramic materials, little work has been reported on the erosion behaviour of $B_4C/TiB_2/C$ ceramic composites. In this study, the erosion wear of $B_4C/TiB_2/C$ ceramic composites with different mechanical properties and microstructures were investigated using abrasive air-jets. The factors that influence the erosion wear behaviour of $B_4C/TiB_2/C$ ceramic composites were analyzed and the erosion wear mechanisms were determined by microstructural analysis by comparison of eroded and polished surfaces.

2. Experimental procedure

Commercial B_4C powder with a particle size of 3–5 μm was used as the starting materials (produced by the second erodent material factory of Peony River, Heilongjiang province, China). TiO_2 with 1–2 μm particle size (produced by Shanghai Taibai Product of Chemistry and Industry Co., Ltd.) were used as additives. B_4C and TiO_2 were milled at certain proportions as indicated in Table 1. Milling was carried out for 100 h in alcohol using a vibratory ball mill with cemented carbide (WC) balls. The milled powders were then washed in 10 mol.% hydrochloric acid to remove metal-mill media impurities. The average particle size of the final milled powders was less than 1.5 μm. After drying the powder, densification of the compacted powder was achieved in a graphite die by uniaxial hot-press sintering at 1900 °C, at a pressure of 35 MPa in a N_2 atmosphere for 50 min. The diameter and thickness of the hot-press sintered green compacts were 50 mm and 6 mm,

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Table 1
Starting compositions of the samples.

Samples	Starting compositions (wt.%)	
	B_4C	TiO_2
NT1	96	4
NT2	92	8
NT3	88	12

respectively. The final relative densities were determined using the Archimedes method and are shown in Table 2.

Some of the sintered compacts were cut into bars for measuring the mechanical properties while the remainder was used for erosion tests. Standard test bars (3 mm × 4 mm × 36 mm) were obtained through rough grinding, finish diamond grinding, and finally polished to a 0.1 μm finish. Three-point-bending mode was used to measure the bending strength using an electronic universal experimental instrument (produced by Jinan TEST Co., Ltd.) with a span of 20 mm at a crosshead speed of 0.5 mm/min. At least twelve specimens were tested for each series of composition in air at room temperature.

Vickers hardness was measured on the polished surfaces with a load of 9.8 N for 5 s using a micro-hardness tester (produced by Shanghai Hengyi electronic testing instrument corporation). Fracture toughness measurements were performed using indentation method. For the fracture toughness determinations the indentations on polished surfaces were generated by the Vickers micro-hardness tester with a diamond pyramid indenter, at a load of 196 N and a loading time of 30 s. The formula proposed by Cook and Lawn [9] was used to calculate the final fracture toughness. Hardness and fracture toughness data were determined using at least 10 indentations on polished surfaces with an Ra of 0.1 μm for each specimen.

Erosion tests were performed under ambient conditions of temperature and humidity over a period of 30 min with an abrasive air-jet machine tool (produced by Qingdao SHIYONG hardware machinery Co., Ltd.). The erodent material used in this study was 150–180 μm SiC powder, of 3.15 g/cm^3 density, 32.8–34.0 GPa hardness and ≥99% purity. NT1, NT2 and NT3 disc specimens with a diameter of 50 mm and thickness of 6 mm were carried out for erosion tests, and the test specimens were located 10 mm from nozzle orifice for all impingement angles. Impingement angles of 15°, 30°, 45°, 60°, 75°and 90° were adopted and the particle velocities of 30 m/s, 45 m/s, 60 m/s and 75 m/s were used. The particle velocity was controlled by means of the compressed air pressure and measured using the rotating double disk technique [10]. Three specimens at each test condition were adopted in order to minimize data scattering and decrease the relative error.

Volume erosion rate was used to rank the erosion behaviour of the B_4C-based ceramic composites, and was calculated using the following equation

$$V = \frac{M}{\rho \times M_p} \quad (1)$$

where V was the volume erosion rate (mm^3/g) of the tested disc specimen, M and ρ were the mass loss (g) and real density (g/mm^3) of the tested disc specimen, respectively, and M_p was the mass (g) of erodent particles used during the test. Mass loss of the tested disc specimen was measured using an analytical balance with an accuracy of 0.1 mg. Prior to weighting the specimens were cleaned using an ultrasonic bath with distilled water for about 10 min. The mass of erodent used in each test is 30 kg. The erodent can be used circularly in each test and the used erodent in previous test will be replaced by new erodent when new test is carried on.

The original polished surfaces and the eroded surfaces of NT2 and NT3 disc specimens were examined in a scanning electron microscope (HITACHI S-570). The phases and phase content for the fabricated B_4C-based ceramic composites were determined using an XRD (D/max-2400).

3. Result and discussion

3.1. X-ray diffraction phase analysis

The X-ray diffraction analysis data of the NT2 specimen hot-pressed at 1900 °C for 50 min is shown in Fig. 1. It was observed that B_4C, TiB_2 and C phases were present, and no trace of TiO_2 phases was detected. The final relative wt.% phase compositions of the three hot-press sintered samples are shown in Table 2.

TiO_2 reacted with B_4C by the following equations [11]

$$B_4C + 2TiO_2 \rightarrow 2TiB_2 + CO_2\uparrow + O_2\uparrow \quad (2)$$

$$B_4C + 2TiO_2 \rightarrow 2TiB_2 + C + 2O_2\uparrow \quad (3)$$

Based on thermodynamic analysis of chemical reactions, the values of ΔG^θ, the Gibbs free energy for Eqs. (2) and (3), were less than zero, which indicated that Eqs. (2) and (3) could occur under these experimental conditions. It is generally agreed that

Table 2
The final compositions, grain size, relative density and mechanical properties of B_4C-based ceramic composites.

Specimens	Relative compositions (wt.%)			Mechanical properties			Grain size (μm)	Relative density (%)
	B_4C	TiB_2	C	Vickers hardness (GPa)	Flexural strength (MPa)	Fracture toughness (MPa m$^{1/2}$)		
NT1	95.7	3.5	0.8	26.3 ± 1.6	435 ± 21	4.1 ± 0.4	5.0	93.6 ± 0.8
NT2	91.8	5.2	3.0	27.6 ± 1.0	551 ± 14	5.2 ± 0.2	3.0	96.2 ± 0.6
NT3	87.4	7.0	5.6	25.4 ± 1.8	553 ± 20	3.9 ± 0.5	2.5	95.5 ± 0.5
Pure B_4C [15]	100	0	0	18.1 ± 2.0	240 ± 25	2.5 ± 0.7	–	86.4 ± 0.5