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Technical Report

Nondestructive evaluation of surface degradation of silicon carbide–cordierite ceramics subjected to the erosive wear

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ABSTRACT

Covalent bond in SiC ceramic request high temperature for its sintering. In order to put down sintering temperature of SiC ceramics we choose cordierite as phase between SiC particles. Reactive sintering is an effective way to produce ceramics at relatively low temperature. We have created in situ SiC/cordierite composite at 1250 °C. Cordierite precursor was made from commercially available spinel, alumina and quartz.

The possibilities of using silicon carbide–cordierite material as resistant to the erosive wear was goal of this investigation. The fluid dynamic system of the experimental methodology was used here to produce ultrasonic erosive wear. Mass loss and level of degradation were measured before and during the experiment. Level of degradation of the samples was monitored using Image Pro Plus program for image analysis. Average erosion ring diameter as well as average erosion area were monitored during experiment. Obtained results pointed out that after 150 min sample exhibited excellent erosion resistance compared to metal and ceramic samples.

1. Introduction

The use of ceramics materials has increased in the last decades within a wide range of applications from electronics to mechanical parts and bio medicine application (hip prosthesis, dental implants). One of the main reasons for that is the improvement of the fracture toughness that allows the ceramic material to perform better when it is subjected to the operating conditions [1–3]. However, there are operating conditions that can produce cavitation erosion on technical ceramics, for example during the operation of bearings, injectors or valves. Hence, the study of the cavitation erosion mechanisms of technical ceramics is of importance to improve their performance in real applications.

Silicon nitride and zirconia as interesting materials with excellent cavitation resistance properties were studied. The erosion mechanism of silicon nitride subjected to cavitation exposure has been studied [3–6]. Previous authors have reported that a larger grain size leads to a larger erosion rate [4,6]. The cracking is mainly intergranular although some cracks are visible within big or elongated grains. These cracks produce erosion pits, most of them showing microcracks extension at the boundaries. This produces pits bridging or coalescence, removing successively more pits [7]. Alumina based castable are reported as the ceramics with the promising cavitation erosion resistance in the literature [8–10].

Cavitation, one of the mechanisms of liquid erosion, characterized by the generation and the collapse of vapor structure in liquid, occurs frequently in hydraulic machinery such as pumps, turbine and propellers. The pressure waves emitted during the collapses of vapor structures interact with neighboring solid surfaces, leading to material damage [1–3]. Cavitation damage is often tested for the metallic materials [11–23]. Investigation of influence of the impact load [13] and possibilities of quantitative evaluation of cavitation erosion were investigated [15]. Most of the research were related to the cavitation wear behavior of different types of steels [16,19–21] as well as different types of alloys and coatings [17,18,23,28,29].

The goal of this investigation was to study possibilities of application of silicon carbide–cordierite based ceramic material for potential use as erosion resistant material.

2. Materials

Cordierite and silicon carbide are ceramic materials suitable for high temperature application with good chemical resistance. Their target application is in furnaces for use at temperatures over 1000 °C. Typical values of selected properties of dense constituents used in refractory materials investigated are given in Table 1. Cordierite precursor was made from commercially available spinel, alumina and quartz. Starting powder materials were mixed

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Table 1
Typical values of selected properties of dense constituents used in refractory materials investigated [24,25].

	Cordierite	Silicon carbide
Chemical formula	$2MgO–2Al_2O_3–5SiO_2$	SiC
Density (g/cm^3)	2.60	3.1
Modulus of elasticity (GPa)	70	410
Poisson ratio	0.21	0.14
Compressive strength (MPa)	350	4600
Fracture toughness (MPa m$^{0.5}$)	–	4.6
Linear thermal expansion coefficient (10^{-6} K^{-1})	1.7	3.1
Hardness (Moss)	7.5	9.5

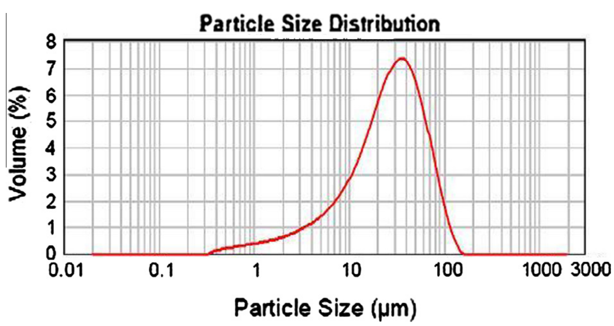

Fig. 1. Particle size distribution of used SiC powder.

Table 2
Theoretical chemical composition of main crystaline phase in SiC/cordierite composite.

Element	Silicon–carbide		Cordierite		Sapphirine	
	at%	wt%	at%	wt%	at%	wt%
Mg			6.89	8.31	10.29	12.33
Al			13.79	18.45	26.47	35.19
Si	50	70.05	17.24	24.01	4.41	6.11
O			62.08	49.23	58.82	46.37
C	50	29.95				

according to the chemical composition of cordierite, $2MgO\ 2Al_2O_3\ 5SiO_2$. After attritor milling and drying mixture was used as starting material for obtaining SiC/cordierite composite ceramics with weight ratio 50:50. Ball milling with Al_2O_3 balls in DI water was performed for mixture homogenization. The powder was pressed into cylinders with 2 cm diameter and approximately 1 cm high and sintered in air at 1250 °C for 3 h with heating rate of 10°/min.

Particle size distribution was determined with The Mastersizer 2000 particle size analyzer. The Mastersizer 2000 uses the technique of laser diffraction to measure the size of particles. It does this by measuring the intensity of light scattered as a laser beam passes through a dispersed particulate sample. This data is then analyzed to calculate the size of the particles that created the scattering pattern. The SiC powder was dispersed in water. As it could be observed from Fig. 1 particle size of used SiC powder is around 30 μm. Results for the particle size distribution are given in Fig. 1.

Results based on XRD and SEM confirmed that structure consists from silicon carbide, cordierite, sapphirine as well as small amount of enstatine. Theoretical chemical composition of main crystaline phase in SiC/cordierite composite is given in Table 2. Formation of cordierite and sapphirine are influenced by attendance of glassy phase based on SiO_2. From SEM micrographs one can see the porous structure of composite ceramics (Figs. 2 and 3).

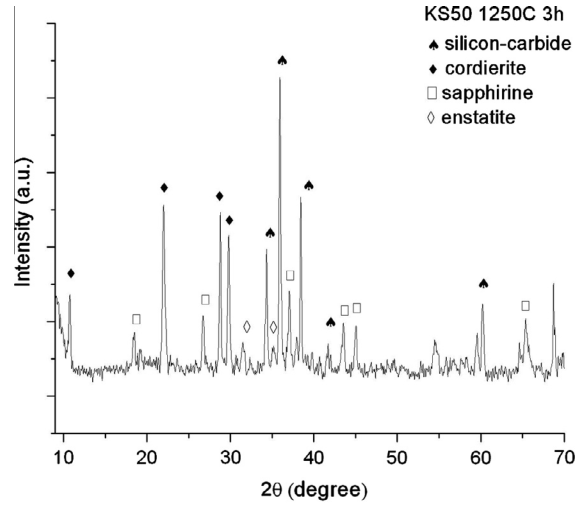

Fig. 2. XRD of the SiC/cordierite composite ceramics samples.

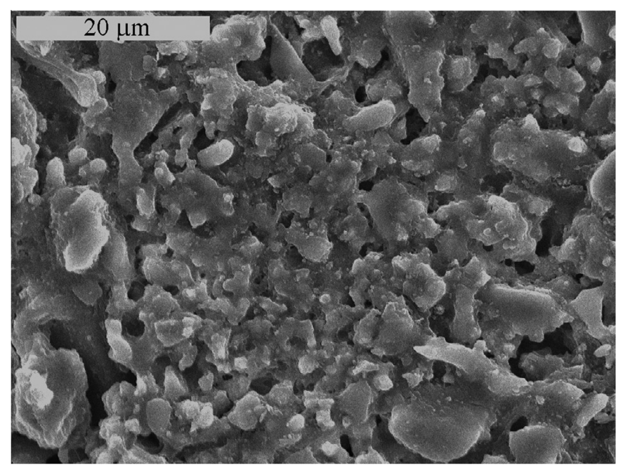

Fig. 3. SEM of the SiC/cordierite composite ceramics sample.

3. Cavitation erosion testing

The fluid dynamic system of the experimental methodology used here to produce ultrasonic cavitation is explained in detail somewhere else [8]. The parameters and geometry of the cavitation erosion test are similar to the equipment described in [7]. Modified vibratory cavitation testing is applied for cavitation erosion determination. Diameter of the horn is 10 mm and distance between the horn and the sample was 2 mm. Samples were disks with diameter 3 cm.

4. Results and discussion

Mass losses of the test specimens were done on an analytical balance with an accuracy of ±0.1 mg. The measurements were performed after subjecting each test specimen to cavitation for 30 min. The duration of the tests was 150 min. Optical microscopy technique was applied to analyze the effect of the erosion and to interpret the results of cavitation tests.